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On the metamorphism produced by the combustion of hydrocarbons in the Tertiary sediments of south-west Persia.[1]

(With Plates IX and X.)

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THE present communication deals with a peculiar series of rocks found in association with the Tertiary sediments so extensively developed in south-west Persia at the head of the Persian Gulf. At one or two localities in that region the marls and limestones are baked, fused, and in some cases so thoroughly recrystallized that at one time they were suspected to be igneous material arising from localized volcanic action. Careful examination of the field occurrences has, however, failed to disclose any trace of volcanicity, whilst petrographical and chemical examination has shown that even the most coarsely crystalline types bear no resemblance to any known igneous rock.

My attention was first directed to these rocks by Mr. H. T. Mayo in 1926 when I was permitted to examine the material collected by Mr. B. K. N. Wyllie, to whom belongs the credit of first discovering these apparently unique occurrences, and to visit the localities, where

[1] Communicated by permission of the Director, H.M. Geological Survey and Museum.

additional material was obtained. The cause of the alteration of the sedimentary rocks at these localities is no longer operative, and is not apparent; that it may most probably be ascribed to the combustion of gas or oil long since extinguished has been made clear by the subsequent investigation of other localities where similar rocks have been, and are being, exposed to such action and have undergone similar changes in structure and mineral composition.

The material on which the present descriptions are based was collected in part by myself in May, 1926, and in part by Messrs. B. K. N. Wyllie, R. S. Mackilligan, J. McAdam, and N. L. Falcon of the Anglo-Persian Oil Company, to all of whom I am indebted not only for specimens but also for most valuable information regarding field occurrences.

Field Occurrence.

The most interesting of the localities and the one where the metamorphism of the sediments seems to have been most extensive and prolonged is a small hill, known as Tul-i-Marmar, situated about 52 miles north-east of Ganaweh, a settlement on the eastern shore near the head of the Persian Gulf (fig. 1). This hill lies on the northern extension of a long anticlinal axis—the Chillingar axis—which is one of the numerous structural lines, trending north-west to south-east, along which the massive accumulation of Tertiary sediments of south-west Persia has been folded. The anticline pitches towards the north-west bringing up the Middle Fars[1] division of the Mio-Pliocene rocks in the core of the fold.

Tul-i-Marmar (fig. 2) forms a conical-shaped hill, rising rather abruptly to a height of about 250 feet above the general level which is here from 1,700 to 1,800 feet above sea-level. The hill is built up of red and green marls with gentle easterly dips of 3–5°. On its western and south-western faces, which are steep, there occurs a curious mass of breccia measuring roughly 100 by 100 feet with highly inclined junctions against the adjacent sediments. The field relations, the nature of the material, and, in places, its roughly centroclinal arrangement strongly suggest at first sight the occurrence of a volcanic vent. The breccia consists of angular blocks of varying size set in a matrix of porous, reddish to pink gypsum. In the field the blocks can be readily divided into two types: (*a*) sedimentary rocks consisting of red and green marl, often very hard and clinkery, black limestone,

[1] Cf. The structure of Asia. Edited by J. W. Gregory, London, 1929, p. 111.

red sandstone or grit; and (*b*) rocks which are either slaggy or essentially and sometimes quite coarsely crystalline. It is the presence of these lava-like slags and crystalline rocks which gave rise to the view that the breccia was volcanic, but the petrographical evidence detailed below shows that they are merely fused and, in some cases, almost thoroughly recrystallized calcareous marls. Traced eastwards over the top of the hill, the breccia is seen to consist more and more of blocks of shattered red mudstone with a gypseous matrix, and it finally grades off into hardened solid mudstone.

The significant features of this interesting occurrence are: (1) the strictly localized nature of the metamorphism; around the base of the small hill are undisturbed and unaltered mudstones; (2) the undoubted sedimentary origin of all the material found in the breccia; (3) the complete absence of any rocks of volcanic origin. These facts seem to indicate that the vent-like structure owes its origin to the escape of gas and oil, probably with explosive force, which shattered the rocks surrounding the orifice and, becoming subsequently ignited, in places fused, recrystallized, and metamorphosed them.

About $3\frac{1}{2}$ miles south-east from Tul-i-Marmar on the north-east side of the river-course known as Darreh Harrachi, and situated above a vertical cliff of limestone of Middle Fars age, there occurs a mass of greenish, vesicular, crystalline rock, roughly about 12 by 8 feet in area. It is surrounded by red and yellow, slightly brecciated marls into which it appears to grade. The mass resembles a dike or rather a plug in its mode of occurrence, but no chilled margins are present and the petrographical character of the rock shows it to be an altered marl. My visit to this locality was somewhat hurried, but since then Mr. N. L. Falcon has made a fresh examination, in the course of which he exposed the base of the crystalline rock by blasting and excavation and proved that it was continuous downwards with baked mudstone underlain by black, bitumen-stained limestone with well-developed vertical joints carrying bitumen. The largest of these joints has blackened walls and it leads up to the area of most intense metamorphism which has thus been proved to be superficial and to be due most probably to the combustion of oil or gas. At one or two other localities in the neighbourhood the sedimentary rocks show secondary jointing, reddening, and hardening, to be ascribed to the same cause, but in no case is the metamorphism accompanied by the extensive brecciation and signs of explosive activity so apparent at Tul-i-Marmar.

The material collected from the above-mentioned localities has been compared with interesting results with specimens from other

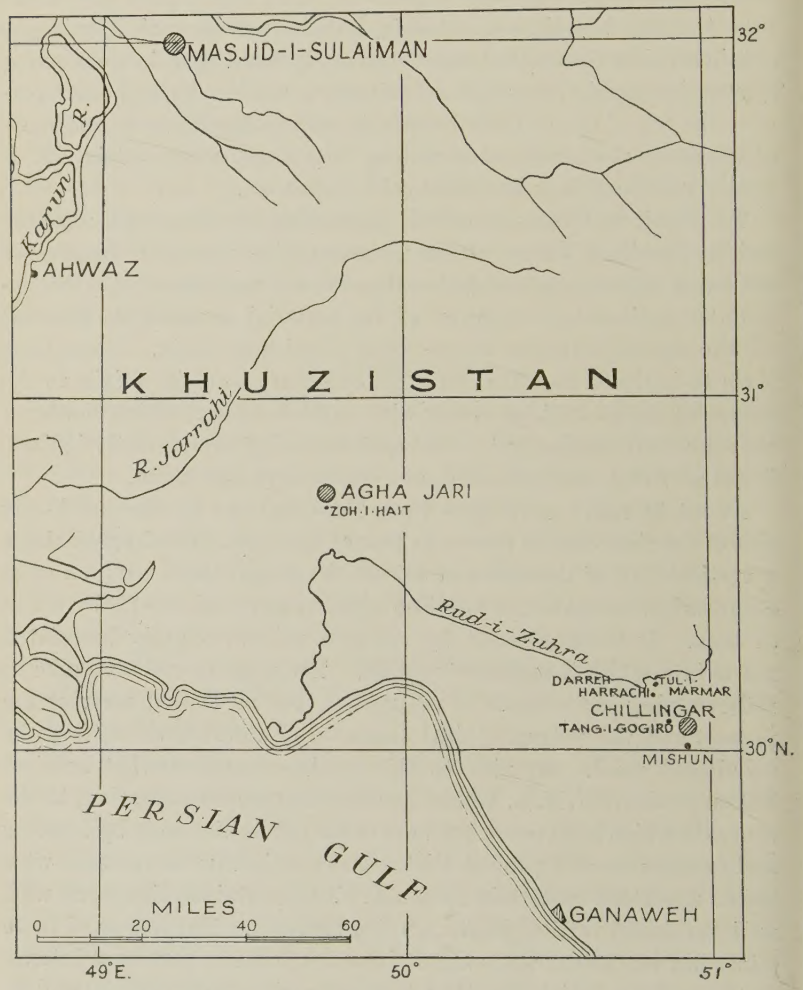


Fig. 1. Sketch-map showing localities referred to in the text.

localities in Persia where burning gas or oil is known to have metamorphosed the Tertiary sediments.

At Zoh-i-Hait, near Agha Jari, about 80 miles north-west of Tul-i-Marmar, spontaneous combustion is still in progress, with the formation of hydrogen sulphide, sulphur dioxide, and sulphur. Partially

burnt bituminous matter and a dark-brown powdery ash which covers the hill-side give rise to a conspicuous black landmark on the edge

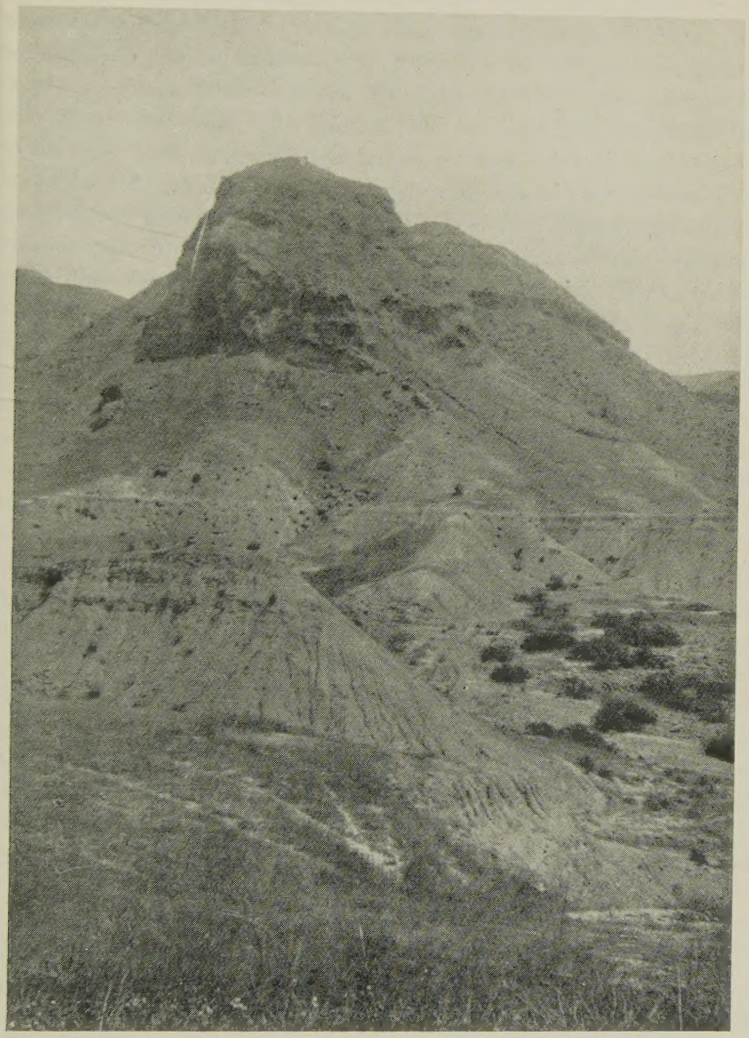


FIG. 2. Western and south-western aspects of Tul-i-Marmar, Persia.

of the plains. The horizon is the base of the Middle Fars and the limestones and marls are, according to Mr. A. J. Goodman, to whom I am indebted for the foregoing particulars, very much indurated by

the heat. Specimens submitted from this locality show that fusion and recrystallization of the marls have taken place with the production of types even more coarsely crystalline than those at Tul-i-Marmar, one remarkable specimen showing large augite crystals up to 2 cm. in length. Mr. B. K. N. Wyllie informs me that similar phenomena occur in Tang-i-Gogird, about 8 miles south-east from Tul-i-Marmar, and he is of the opinion that they arise from the exhalation of hydrocarbon gases and hydrogen sulphide from oil or gas accumulations in or below the Lower Fars strata. By oxidation the hydrogen sulphide gives rise to sulphates forming a grey, powdery gypseous clay containing some aluminium sulphate, and known locally as gach-i-tursh (= sour gypsum). In such areas crater-like holes lined with sulphur crystals and emitting sulphurous gases are common. Should the gases leak to the surface and ignite, the conditions necessary for the metamorphism seen at Zoh-i-Hait and Tang-i-Gogird are set up, whilst if there is a sudden release of gas accumulated and held at high pressure the phenomena of Tul-i-Marmar are produced.

At various places in the oil-fields fused and partially crystallized rocks have been produced from Tertiary sediments by the action of burning gas or crude oil during the process of drilling wells. Samples have been examined from such artificial occurrences at Masjid-i-Sulaiman, the principal Persian oil-field, and at Naft Khaneh, about 22 miles south of Khanaqin, on the Persian-Iraq frontier. Owing to the short time during which the fire lasted and the necessarily rapid rate of chilling of the molten material, the metamorphosed material tends to be glassy and slag-like, yet it shows in places a mineral development quite comparable with that of the more thoroughly crystallized and, presumably, more slowly formed, products of the natural occurrences.

Petrography.

1. Tul-i-Marmar.—The rocks found in the breccia of Tul-i-Marmar comprise a considerable variety of types. The sediments present include gypsiferous rock-salt, hardened green and red marls and mudstones, calcareous fine-grained and reddish grits showing under the microscope angular grains of quartz, felspar, and mica set in a calcareous matrix. Blocks of a peculiar dense-black fine-grained limestone are plentiful. Under the microscope this rock is seen to be a fossiliferous limestone with numerous organic remains set in a

recrystallized matrix of calcite. The organic fragments are surrounded and frequently completely permeated by a black deposit of carbon which sometimes forms lustrous reniform masses on the surface of specimens and resembles the carbon deposited on the walls of high-temperature gas furnaces. The rock is obviously a recrystallized limestone, originally impregnated with hydrocarbons which have been decomposed by heat, leaving residual carbon which imparts the jet-black colour.

The most interesting rocks in the breccia are, however, the marls and calcareous sandstones which have undergone fusion and recrystallization. They vary in texture from exceedingly fine-grained, greenish, flinty looking types to comparatively coarsely crystalline rocks, with constituent minerals measuring up to 2–3 mm. in length. Vesicles, either empty or lined with calcite or gypsum, or both, are common, and not infrequently are so abundant as to give the rock a pumiceous appearance. In the less altered specimens the original structure of the marl is tolerably well preserved, the only apparent changes being a recrystallization of calcite and the development of yellowish clots and strings composed, apparently, of extremely minute, granular crystals of yellowish-green pyroxene (F. 3052,[1] F. 3040, F. 3053). With advancing alteration and fusion the marl gives place to a granular aggregate of greenish-yellow, finely crystalline pyroxene with glass in which are set irregular crystals of turbid wollastonite with corroded outlines and granular inclusions of pyroxene. The rock is now highly vesicular, the vesicles containing calcite and a turbid, finely crystalline substance, probably anhydrite. Clots of turbid, undigested marl are also present (F. 3041, F. 3043).

Two distinct types of structure, probably to be ascribed to different fusibilities and rates of cooling, are present. In the one type where fusion was presumably more gradual, the structure might fittingly be termed porphyroblastic, turbid porphyroblasts of wollastonite and yellowish augite being set in an exceedingly fine-grained, undifferentiated matrix which invades the porphyroblasts (F. 3031). With more complete recrystallization a rock consisting of a mosaic of more or less equant subidiomorphic crystals of wollastonite, greenish augite, and plagioclase (var. bytownite) is produced. Irregularly-shaped spaces between these minerals are filled by a colourless glass of low refractive index, enclosing laths of wollastonite and bytownite with

[1] The numbers refer to the collection of slides of the Geological Survey and Museum.

rounded crystals of augite. Vesicles filled with recrystallized calcite are common, and a few residual clots of turbid marl with cloudy porphyroblasts of wollastonite occur sporadically throughout the rock (F. 3025, F. 3037). The coarser-grained types showing this structure are not always the most thoroughly crystalline. Thus, in the fine-grained types, with crystals measuring 0·2 by 0·06 mm., the amount of residual, undigested sediment may be negligible, whilst specimens in which the porphyroblasts of wollastonite and augite measure up to 1·5 by 0·4 mm. may contain quite a substantial proportion of turbid marl showing as its only recognizable signs of alteration recrystallization to calcite, particularly in zones surrounding and invading the wollastonite (F. 3028).

Rocks showing the second type of structure are composed of crystals of *acicular* habit and resemble much more closely the artificial products arising from the fusion of marls at the oil-fields (see below). The finer-grained types of these rocks, which are usually highly vesicular, consist of very minute acicular crystals of pyroxene, wollastonite, and plagioclase, measuring 0·1 mm. in length, and even less, set in a turbid, undifferentiated matrix with patches of recrystallized calcite (F. 3033). Some of them contain original quartz grains incompletely digested; these exhibit all degrees of corrosion and are surrounded either by isotropic rims or by confused aggregates of wollastonite, augite, and recrystallized calcite, which ultimately replace them. Inversion to tridymite or cristobalite has not been observed (F. 3035, F. 3038). In the coarser types the same minerals are present, but the turbid matrix is now replaced by patches of isotropic glass in which crystals of wollastonite, augite, and plagioclase have developed. The vesicles are filled with recrystallized calcite, often surrounded by a zone of isotropic glass, and occasionally containing crystals of the silicate-minerals already mentioned (F. 3026). As in the case of the porphyroblastic types, here also the more coarsely crystalline rocks may show a larger proportion of residual marl than the finer-grained ones (F. 3037).

Although pyroxene, wollastonite, and plagioclase (var. bytownite) are the silicates most commonly developed in the recrystallized sediments of Tul-i-Marmar, other minerals are exceptionally present either in some of the more coarsely crystalline rocks or in those which, whilst of very fine grain, seem to have been almost completely recrystallized. Thus some of the coarser, acicular types, in hand-specimens resembling fine-grained syenites, under the microscope are

seen to consist of pale-green aegirine-augite, as crystals measuring up to 3 mm. in length, clear laths of wollastonite, 1·2 by 0·12 mm., and rectangular, leather-brown crystals of melilite, 1 by 1 mm. There are no traces of turbid residual sediment in the sections, but the angular spaces between the crystals are filled with an aggregate of needles of deep-green pleochroic pyroxene, wollastonite, turbid melilite, recrystallized calcite, and isotropic glass (F. 3030). Other sections show areas of clear transparent glass in which are developed large crystals of colourless pyroxene, clear wollastonite, plates of bytownite felspar, and large exceedingly turbid imperfectly-formed crystals of melilite enclosing recrystallized calcite and occasional crystals of the other minerals. Vesicles filled with microcrystalline anhydrite, into which project crystals of augite, wollastonite, and melilite, are common (F. 3061). A still more remarkable rock consists of crystals of honey-yellow to green pleochroic aegirine, clear yellowish-brown melilite as crystals up to 2 mm. in length, clear wollastonite, and large clear patches of a mineral which is not quite isotropic but shows the characteristic anomalies and refractive index of leucite; included in these clear areas are crystals of aegirine and wollastonite, veins and patches of recrystallized calcite, and dark turbid rod-shaped masses altering in places to wollastonite, and representing, probably, vestigial sediment (F. 3062).

Similarly, in the coarse-grained porphyroblastic types the areas of turbid marl give rise in the first place to rectangular elements full of inclusions surrounded by clear isotropic glass and finally to leather-brown melilite (F. 3060, F. 3068, F. 3029). Fine-grained vesicular rocks, consisting of irregularly-shaped porphyroblasts of yellow aegirine set in a clear colourless matrix of finely-crystallized melilite, have also been noted and recall the types so common at Darreh Harrachi (F. 3065, F. 3096).

II. Darreh Harrachi.—The altered rocks at this locality are fine-grained tough greenish porcellanous types with minute vesicles which are usually empty. Under the microscope they occasionally show acicular crystals of green pyroxene, wollastonite, and bytownite with glass and recrystallized calcite (F. 3088), but typically they are fine-grained porphyroblastic rocks consisting of a matrix of colourless melilite built up of exceedingly minute square-shaped crystals in which are set spongy imperfectly-crystallized masses of pyroxene and wollastonite, riddled with inclusions of melilite. When the pyroxene is colourless, wollastonite is rare and the melilite is distinctly

birefringent, but when the pyroxene is yellow and, apparently, approaching aegirine in composition, wollastonite is abundant and the melilite is almost isotropic (F. 3080, F. 3090, F. 3084, F. 3093).

Some of these rocks are unique amongst natural occurrences in that they contain pseudo-wollastonite, a mineral hitherto known only in artificial material. It has been detected in three slides (F. 3083, F. 3085, F. 3092), where it builds irregularly-shaped crystal grains, 0·1 by 0·05 mm., showing typical cleavage and optical properties (p. 219). It occurs in intimate association with melilite, yellow pyroxene, and with wollastonite, a point of considerable interest bearing on the conditions under which the rocks were formed. Wollastonite and pseudo-wollastonite have been noted, not only in the same microscopic field but also in the same mineral grain, which may consist of a core of pseudo-wollastonite surrounded and apparently in process of replacement by the other modification (F. 3083).

III. Zoh-i-Hait, near Agha Jari.—Only two specimens are available from this locality, where, as already mentioned, marls are at present in process of metamorphism by spontaneous combustion. One of these (F. 3095) is a greenish-grey rock with irregularly-shaped masses of a brown substance scattered throughout the specimen. Vesicles are common and are either empty or filled with a white chalky-looking substance. A section shows large crystals of colourless idiomorphic pyroxene, up to 2 mm. in length, with occasional laths and plates of bytownite set in a matrix consisting of finely granular pyroxene and large brown masses of turbid isotropic glass enclosing crystals of pyroxene and plagioclase felspar. The vesicles are filled with recrystallized calcite and turbid gypsum and are invaded by the surrounding material. Wollastonite is rare, but throughout the slide there are fibrous turbid aggregates, showing very rarely incipient wollastonite. This rock bears a remarkable resemblance to one from Tul-i-Marmar (F. 3061) from which it differs in having brown turbid glass in place of melilite, gypsum in place of anhydrite in the vesicles, and an aggregate of turbid fibrous material in place of wollastonite. Otherwise the rocks are identical in structure and mineral development, the one being merely a more thoroughly recrystallized representative of the other.

The other specimen (F. 3094) is the exceedingly coarse-grained rock already referred to (p. 212). Under the microscope large idiomorphic crystals of colourless augite (up to 2 cm. in length) are set in a turbid matrix consisting of acicular crystals of augite, very

occasional plagioclase felspar, and long turbid fibrous growths which appear to consist of recrystallized calcite and a finely fibrous or granular aggregate of anhydrite.

IV. Masjid-i-Sulaiman and Naft Khaneh.—The fused and partially recrystallized marls from these two localities were produced by jets of burning oil and gas playing on surface material and, in consequence of the rapid chilling, are never coarsely crystalline. They consist essentially of acicular crystals of pyroxene, colourless to pale-yellow, and wollastonite in an isotropic matrix which may be clear and transparent or turbid and full of inclusions. In the more slowly cooled and more crystalline types the rocks resemble the finer-grained acicular types from Tul-i-Marmar, and there can be no doubt that with more prolonged heat and slower cooling rocks identical with the more coarsely crystalline ones from that locality would have been produced.

Pseudo-wollastonite has been detected in three of the specimens. In the first (F. 3098), from Masjid-i-Sulaiman, it forms a black selvage, 0·5 cm. thick, on a dark-green vesicular rock. Under the microscope this selvage is seen to consist of pure pseudo-wollastonite as sheaf-like aggregates, prismatic crystals, and skeletal growths, with subordinate glass; the rock itself consists of acicular wollastonite and augite with the usual turbid matrix.

In two sections from Naft Khaneh (F. 3102, F. 3104), showing yellowish pyroxene and wollastonite as acicular crystals in turbid glass, pseudo-wollastonite occurs as minute prisms and irregularly-shaped grains in isolated areas.

Mineralogy of the Metamorphosed Sediments.

(*a*) *Pyroxene.*—The pyroxene, which is always present in the slides, shows considerable variation in optical properties. When idiomorphic, its habit is prismatic parallel to the *c*-axis and the typical (110) cleavage is well developed. It varies from colourless to fairly deep greenish-yellow and is frequently zoned, crystals occurring with colourless cores and greenish margins; it is always fresh and shows no signs of decomposition. The colourless variety appears to be a typical *diopside*, optically positive, with approximate refractive indices $\alpha = 1{\cdot}665$, $\beta = 1{\cdot}680$, $\gamma = 1{\cdot}700$. The maximum extinction $\gamma : c$ is 42°. With increasing refractive index and decreasing extinction-angle the colour gradually deepens through pale-green to a honey-yellow variety which appears to be a true *aegirine*, or at

least an aegirine-augite very rich in the aegirine molecule. It occurs as prisms, (100) and (010), with well-developed cleavage and pronounced pleochroism, α = pale-green, β = yellowish-green, γ = honey-yellow. The approximate refractive indices are $\alpha = 1{\cdot}760$, $\beta = 1{\cdot}800$, $\gamma = 1{\cdot}810$, $2V = 84$–$90°$, optically negative with pronounced inclined dispersion, $\rho > v$. From approximate measurements on the universal stage, $\alpha : c = 14°$, and the cleavage-angle $(110) : (1\bar{1}0) = 86°$. Unfortunately this interesting mineral, which occurs in association with leucite, melilite, and wollastonite, has been detected in quantity only in one small specimen and, although renewed search has been made, sufficient material for a satisfactory analysis is not at present available; but that it approaches an aegirine in composition is certain.

(*b*) *Wollastonite.*—This mineral is a common constituent of the altered rocks, in some cases being developed as crystals up to 2 mm. in length. They are usually elongated along the *b*-axis and tend to be tabular parallel to (100). The faces recognized in the sections are (100), (001), (102), ($\bar{1}$01), and cross-sections show the three typical cleavages parallel to (100), (001), and ($\bar{1}$01). Such sections show the maximum birefringence and peculiar mottled extinction noted by Dr. Osborne,[1] with extinction $\alpha : c = 33°$. Twinning on (100) is common and is sometimes repeated. The mineral is optically negative with small, and slightly variable, axial angle; $\alpha = 1{\cdot}617$, $\beta = 1{\cdot}628$, $\gamma = 1{\cdot}630$.

In the more completely crystallized specimens the crystals are clear and transparent but are frequently veined with crystalline calcite. In the rocks with a considerable proportion of residual sediment the crystals are always turbid and show rounded corroded outlines against the matrix which invades them. At the junction there is usually a sheath of turbid recrystallized calcite, and the inclusions of marl in the crystals show all stages of recrystallization to that mineral. The turbidity of the wollastonite is due to minute gas cavities; whilst the rounded outlines, and the sheaths, veins, and inclusions of calcite seem to have arisen from reaction between the marl and the wollastonite when the rock was heated up, rather than from ordinary weathering subsequent to cooling. Otherwise it is difficult to explain the fresh condition of the wollastonite in the more completely recrystallized material (F. 3027, F. 3028, F. 3030, F. 3060–3).

[1] G. D. Osborne, The contact metamorphism and related phenomena in the neighbourhood of Marulam, New South Wales. Geol. Mag., 1931, vol. 68, p. 295.

(*c*) *Pseudo-wollastonite.*—The rarity of this modification of calcium metasilicate in the fused and recrystallized marls affords some indication of the maximum temperature at which the minerals separated out, it being the stable form above 1200° C.[1] It builds irregular grains, 0·1 by 0·05 mm., or irregular prisms, with corroded outlines and traces of a cross-cleavage parallel to the basal plane. It is fresh and undecomposed and may be readily identified by its high birefringence, its practically uniaxial figure in basal sections, optically positive sign, and its refractive indices (determined in oils) $\omega = 1{\cdot}614$, $\epsilon = 1{\cdot}648$. Basal sections might be mistaken for granular calcite but the positive optical sign is diagnostic. In the specimens from Darreh Harrachi it always occurs in sporadic areas throughout the aggregate of melilite crystals comprising the bulk of the rock and associated with a deep-brown isotropic material which is probably glass. Partial reversion to wollastonite has been noted, the two forms being readily identifiable in the same grain.

(*d*) *Plagioclase.*—The felspar noted in the slides is always a plagioclase of the composition of bytownite. It seems to have been the last of the silicate-minerals to form and occurs as clear irregularly-shaped plates between the other minerals, which it encloses. It shows the usual cleavage and polysynthetic twinning, and is optically negative with a large axial angle and a mean refractive index of 1·573 (F. 3063). In the rocks where the felspar is best developed there is usually a considerable amount of clear, colourless, isotropic glass containing crystals of pyroxene. This glass has probably the approximate composition of bytownite which appears to have replaced it when cooling was sufficiently slow (F. 3027).

(*e*) *Melilite.* This mineral shows considerable variation in optical properties and doubtless several varieties are present in the specimens. In the coarser types of rocks from Tul-i-Marmar it builds leather-brown crystals up to 2 mm. in length showing good cleavage in the rectangular sections. Such crystals may be transparent and free from inclusions (F. 3052), but usually they are turbid and enclose calcite, wollastonite, and pyroxene. Peg-structure is common. In some sections large rectangular individuals are composed of leather-brown birefringent rims surrounding turbid cores of unidentified material, and all stages occur from such perimorphs to tolerably homogeneous crystals with brown doubly refracting rims and isotropic

[1] G. A. Rankin and F. E. Wright, The ternary system CaO–Al_2O_3–SiO_2. Amer. Journ. Sci., 1915, ser. 4, vol. 39, p. 5.

cores. The deep-brown material is distinctly pleochroic, and in prismatic sections showing cleavage the ray vibrating parallel to the cleavage, i.e. the ordinary ray since the cleavage is presumably basal, is pale-brown, whilst the ray vibrating across the cleavage is deep-brown; in the paler and more homogeneous crystals, however, the ordinary ray is the more deeply coloured. Between crossed nicols sections extinguish straight and show the usual blue polarization colours, but they are rarely uniform and show mottling and zoning. In the blue-polarizing zones, the ray of lesser velocity vibrates parallel to the cleavage and the mineral is negative; the reverse relation holds good for zones showing grey polarization colours and the mineral is positive. In parallel light these sections may appear quite uniform but they seem to be built up of zones of melilite of slightly different optical properties and composition, arranged roughly parallel to the basal plane. For this reason the mean refractive index is difficult to determine; it varies from 1·632 to 1·635 (F. 3030, F. 3061–2), the brown melilite being probably a mixture of åkermanite and humboldtilite in variable proportions.[1]

A colourless melilite, as exceedingly small rectangular crystals, is well developed in the material collected from Darreh Harrachi and sometimes forms the major portion of the altered rocks. It polarizes in pale greyish-blue colours with straight extinction and is always optically positive with a mean refractive index of 1·643 (F. 3084).

(*f*) *Leucite.*—In one slide (F. 3062) this mineral occurs as large irregularly-shaped plates, up to 2·6 by 2·1 mm., clear and colourless, showing under crossed nicols characteristic polysynthetic twinning. The birefringence is in the majority of cases very weak but the twin-structure is usually revealed by the gypsum plate. The leucite is in intimate association with aegirine, wollastonite, and pale-brown melilite; and it encloses crystals of these three minerals. Other inclusions consist of rod-shaped turbid bodies which sometimes enclose small crystals of aegirine or wollastonite. The refractive index is 1·509. Irregular cracks traversing the plates are filled with finely crystalline calcite.

(*g*) *Vesicle Minerals.*—In the finely crystalline types the vesicles are usually filled with crystalline calcite associated with a finely crystalline aggregate of gypsum (optically positive, refractive indices 1·52–1·53), but with increasing alteration and crystallization the

[1] A. F. Buddington, Natural and synthetic melilites. Amer. Journ. Sci., 1922, ser. 5, vol. 3, pp. 66 and 78.

character of the vesicle minerals changes. Gypsum becomes rarer and is replaced by a turbid finely crystalline material with much higher refractive index, in some cases up to 1·614, which approaches anhydrite in character; calcite may give place to a zone of isotropic, slightly turbid glass containing crystals of plagioclase, pyroxene, and wollastonite, with a core of calcite showing highly irregular outlines against the glass which appears to be invading it. In some slides all stages can be seen from vesicles filled entirely with calcite to those filled with glass containing small crystals of the silicate-minerals and having at the centre a minute scrap of crystalline calcite. Such vesicles are not so sharply demarcated from the surrounding rock as those filled entirely with calcite; their boundaries are replaced by crystalline aggregates of pyroxene, wollastonite, and plagioclase until finally the vesicle is practically obliterated by an aggregate of these minerals with glass and occasional calcite (F. 3026). It thus seems clear that the calcite present in the vesicles, and throughout the slides, is not a product of weathering but has resulted from the recrystallization of carbonate of lime in the marl and has participated in the reactions brought about by increasing temperature.

Wollastonite is another mineral which seems to show reaction phenomena. In some of the more coarsely crystalline, porphyroblastic types it is rarely idiomorphic and shows obvious signs of corrosion against the turbid matrix. The actual junctions are marked by sheaths of recrystallized calcite, and when a crystal adjoins a calcite-filled vesicle the latter invades the wollastonite.

The reaction $CaCO_3 - SiO_2 = CaSiO_3 + CO_2$ is a reversible one, but no signs of free silica have been detected around the margins or in the neighbourhood of the inclusions of the wollastonite crystals. There is, however, a large amount of turbid material into which silica may have disappeared.

Chemical Analyses.

The analyses indicate that the rocks bear no relation to known eruptive types and are merely fused and recrystallized sediments whose non-volatile constituents were silica, lime, alumina, magnesia, with subordinate amounts of alkalis and iron oxides. This is most clearly brought out when the Niggli values in the appended table are plotted on a standard diagram (fig. 3), from which it will be seen that

the rocks lie in the area of chemical sediments and well beyond the eruptive field.

	1.	2.	3.	4.	5.
SiO_2	44·73	45·11	43·29	42·35	41·69
Al_2O_3	10·30	9·63	9·27	8·71	9·59
Fe_2O_3	3·89	3·64	4·01	2·78	0·76
FeO	1·28	1·22	0·56	0·72	3·75
MgO	5·77	5·87	8·40	8·67	5·32
CaO	24·19	25·17	28·83	31·77	32·82
Na_2O	1·60	2·26	1·37	1·53	4·76
K_2O	2·72	0·83	2·16	1·51	0·68
$H_2O > 105°$	0·48	2·46	0·33	0·20	0·29
$H_2O < 105°$	0·42	0·72	0·15	0·20	0·05
TiO_2	0·85	0·83	0·73	0·68	—
P_2O_5	0·15	0·14	0·15	0·07	—
CO_2	3·04	2·07	0·65	0·42	—
SO_3	0·95	0·40	0·14	0·25	—
Cl	0·02	0·00	0·00	0·00	—
Cr_2O_3	0·02	0·02	0·02	0·02	—
Li_2O	0·00	0·00	0·00	0·00	—
Total	100·41	100·37	100·06	99·88	99·71

1. Fused Marl. Tul-i-Marmar, Chillingar, Persia. (Analyst, B. E. Dixon.) F. 3027. Composed essentially of wollastonite and green augite, subordinate bytownite and glass, together with remnants of unfused marl. Vesicles are filled with calcite and gypsum.

2. Fused Marl. Tul-i-Marmar, Chillingar, Persia. (Analyst, B. E. Dixon.) F. 3030. Composed essentially of large crystals of wollastonite, aegirine-augite, and pale-brown melilite, with an interstitial mixture of calcite and isotropic matter containing small crystals of aegirine-augite, melilite, and wollastonite.

3. Fused Marl. Tul-i-Marmar, Chillingar, Persia. (Analyst, B. E. Dixon.) F. 3029. Composed of large crystals of augite and turbid wollastonite, with subordinate melilite, in a turbid matrix of small crystals of melilite, and isotropic material that occasionally shows the optical anomalies of leucite.

4. Fused Marl. Darreh Harrachi, Chillingar, Persia. (Analyst, B. E. Dixon.) F. 3084. Composed of porphyritic lath-shaped crystals of diopside in a matrix of minute rectangular crystals of melilite.

5. Humboldtilite from Monte Somma, Vesuvius. (Analyst, H. S. Washington.) See A. F. Buddington, Amer. Journ. Sci., 1922, ser. 5, vol. 3, p. 76.

Table of Niggli Values.

	1.	2.	3.	4.
al	12·6	11·75	9·9	8·9
fm	26·3	26·2	29·0	27·5
c	54·1	56·2	56·0	59·4
alk	6·9	5·75	5·1	4·2
c/fm	2·06	2·14	1·9	2·16

In the absence of separate analyses of the various crystalline phases present it is impossible to calculate even approximately the mineral proportions from the bulk analyses, any such calculation being rendered highly speculative by the complexity and, to some extent, the uncertain composition of melilite,[1] the presence of glass and turbid undifferentiated material of unknown composition, and the zoned

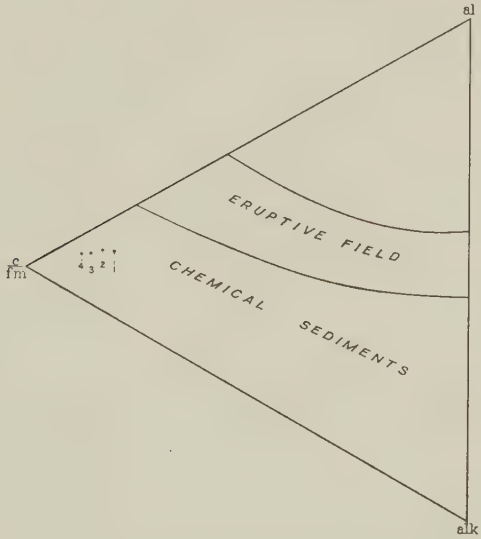


Fig. 3. Diagram showing the relation of the analysed rocks to known eruptive types.

structure of many of the crystals which are often full of inclusions. In the majority of cases the lime, magnesia, and silica combined to form diopside, wollastonite, and melilite, whilst the alkalis combined with the anorthite molecule to form bytownite or, alternatively, with the iron oxides and silica to form aegirine; occasionally the potash formed leucite.

The rock from Darreh Harrachi (analysis 4) contains no glass and represents perhaps the most metamorphosed of all the sediments. It consists of melilite in which are set crystals of colourless diopside showing highly irregular, corroded outlines against the melilite. In this case the alumina, alkalis, and iron oxides must be present in an exceedingly complex melilite consisting of a mixture of åkermanite

[1] A. F. Buddington, On some natural and synthetic melilites. Amer. Journ. Sci., 1922, ser. 5, vol. 3, p. 87.

($2CaO.MgO.2SiO_2$) and gehlenite ($2CaO.Al_2O_3.SiO_2$) with the compounds $3CaO.Al_2O_3.3SiO_2$, $3CaO.Fe_2O_3.3SiO_2$, $3Na_2O.Al_2O_3.3SiO_2$, and $3K_2O.Al_2O_3.3SiO_2$. An analysis of such a melilite is quoted (no. 5) for comparison.

Tilley and Harwood [1] have shown that the incorporation of lime into a dolerite magma leads ultimately to the formation of åkermanite, gehlenite, and pseudo-sarcolite at the expense of diopside and anorthite. There can be little doubt that the abundance of melilite, the absence of bytownite and calcite, and the corroded appearance of the residual crystals of diopside in some of the Persian rocks are due to such reactions, which seem to mark the final stage in the metamorphism of the calcareous sediments. In summary, the initial effect of heat has been the production of diopside, aegirine, wollastonite, bytownite, and melilite (åkermanite), with residual recrystallized calcite; the final effect is the formation of abundant melilite, of complex composition, and colourless diopside. The fact that pseudo-wollastonite is occasionally present in the more altered types (p. 216) indicates that the temperature must have been high.

The literature contains numerous accounts of the occurrence of burning oil or gas, but petrological and mineralogical details of the metamorphic changes, if any, thereby induced are scanty. That the phenomenon may persist for a long time is proved by the account of the celebrated chimaera, in Lycia, which has apparently been in action for over 3,000 years.[2] Widespread alteration of the Monterey Shale from the spontaneous combustion of the hydrocarbon content is recorded by Arnold and Anderson,[3] who show that at widely separated localities the shale is hardened and reddened and eventually converted into a hard vesicular rock, the altered rock sometimes occupying an area of half a square mile. They also record the occurrence of such reddened shale from borings at a depth of 950–1,040 feet. Sir John Cadman [4] has described the formation of a mud volcano in Trinidad in November, 1911, accompanied by the violent eruption of enormous quantities of

[1] C. E. Tilley and H. F. Harwood, The dolerite-chalk contact of Scawt Hill, Co. Antrim. Min. Mag., 1931, vol. 22, p. 463.

[2] E. Tietze, Beiträge zur Geologie von Lykien. Jahrb. Geol. Reichsanstalt, Wien, 1885, vol. 35, p. 359.

[3] R. Arnold and R. Anderson, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California. Bull. U.S. Geol. Survey, 1907, no. 322, p. 48.

[4] J. Cadman, Notes on the development of the Trinidad oilfields. Journ. Inst. Petrol. Techn., 1915, vol. 1, p. 106.

inflammable gas. This became ignited, probably by sparks from the abrasion of pyritic fragments, and produced a flame 300 feet high which burnt for fifteen hours, when it subsided and became extinguished.

There is thus ample corroboration of the explanation suggested for the Persian occurrences, which, however, appear to be unique in that the rocks affected were originally calcareous marls of such composition that new mineral combinations were readily formed at the temperatures available.

I am greatly indebted to Sir John Cadman, G.C.M.G., through whose kindness I was enabled to visit Persia and who has given his consent to the publication of the results. My thanks are also due to my colleagues, Dr. J. Phemister, who accompanied me in the field, and Dr. W. Q. Kennedy for much helpful criticism.

Explanation of Plates IX and X.

Fig. 1. F. 3031.[1] Small corroded porphyroblasts of wollastonite (white) in a turbid undifferentiated matrix; large rounded white areas are empty vesicles. Ordinary light. × 39. Tul-i-Marmar, Chillingar, Persia.

Fig. 2. F. 3025. Clots of marl, dark in photograph, surrounded and in process of replacement by a mosaic of small crystals of wollastonite, augite, and plagioclase, which constitute the bulk of the rock. Ordinary light. × 39. Tul-i-Marmar.

Fig. 3. F. 3028. Large crystals of wollastonite, with irregular outlines sheathed with calcite, and augite in a turbid undifferentiated matrix. The vesicles are occupied by calcite or glass. Ordinary light. × 33. Tul-i-Marmar.

Fig. 4. F. 3093. Corroded crystals of diopside, light in photograph, in a fine-grained matrix of melilite, dark in photograph. Nicols crossed. × 37. Darreh Harrachi, Chillingar, Persia.

Fig. 5. F. 3027. Large acicular crystals of turbid wollastonite, augite, and bytownite, with residual clots of turbid marl. The vesicles are filled with crystalline calcite or, occasionally, leucite or glass. Ordinary light. × 34. Tul-i-Marmar.

Fig. 6. F. 3030. The large, rectangular, turbid crystal in the centre is leather-brown melilite. A large acicular crystal of aegirine-augite lies immediately above it. The white crystals are wollastonite. Interstitial material consists of wollastonite, augite, melilite, and calcite. Ordinary light. × 37. Tul-i-Marmar.

[1] The numbers refer to the collection of slides of the Geological Survey and Museum.

FIG. 7. F. 3062. The large crystal, with good cleavage, stretching across the centre is aegirine. Above it, to the left, is leucite with inclusions of aegirine and brown turbid material. Beneath it is leucite succeeded by laths of wollastonite and aegirine with clear melilite to the right. Ordinary light. × 31. Tul-i-Marmar.

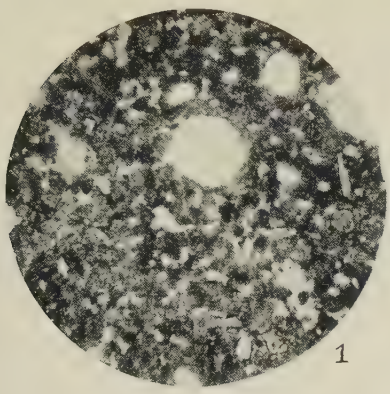
FIG. 8. F. 3061. Vesicle filled with anhydrite in a coarsely crystalline rock consisting of diopside, wollastonite, bytownite, melilite, and glass. A large cleaved prism of diopside projects into the vesicle at the left bottom corner; seated upon it is a crystal of wollastonite. Turbid melilite and, beneath it, clear diopside occupy the centre of the vesicle. The large white rectangular crystal on the top left margin of the vesicle is bytownite with its innermost corner replaced by turbid melilite. Ordinary light. × 33. Tul-i-Marmar.

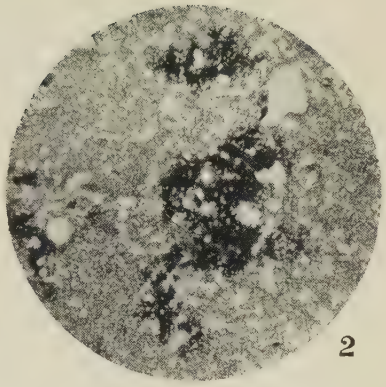
FIG. 9. F. 3083. Pseudo-wollastonite, clear, as corroded grains and prisms, set in a vesicular matrix of partially isotropic melilite. Nicols crossed. × 45. Darreh Harrachi, Chillingar, Persia.

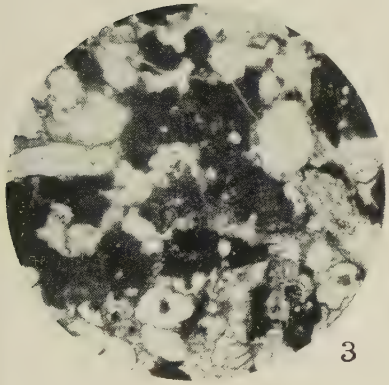
FIG. 10. F. 3026. Vesicular rock consisting of acicular crystals of augite, wollastonite, and bytownite. The lower vesicle is filled with calcite; the upper one has a rim of glass, black in photograph, with a core of calcite in process of replacement by the silicate-minerals. Nicols crossed. × 40. Tul-i-Marmar, Chillingar, Persia.

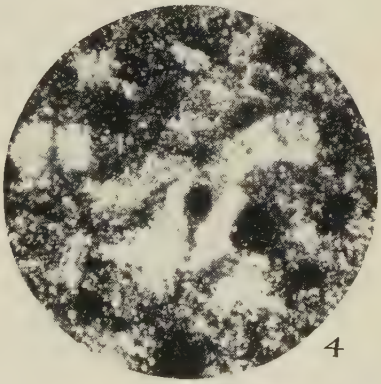
FIG. 11. F. 3094. Large idiomorphic diopside crystals in an imperfectly crystallized matrix consisting of diopside, occasional plagioclase, and turbid acicular growths suggesting incipient wollastonite. Ordinary light. × 32. Zoh-i-Hait, Agha Jari, Persia.

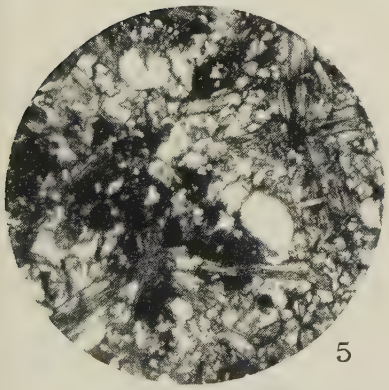
FIG. 12. F. 3098. The clear, upper area is pseudo-wollastonite. The rock in the lower part of the photograph consists of small acicular crystals of wollastonite and augite. Ordinary light. × 42. Masjid-i-Sulaiman, Persia.

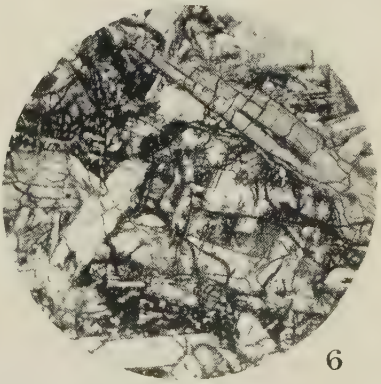












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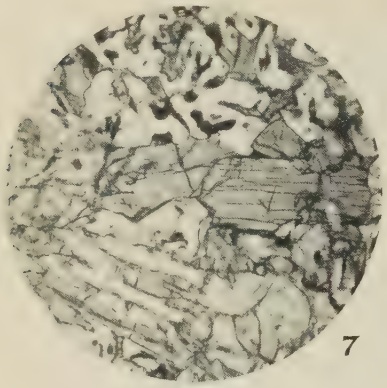
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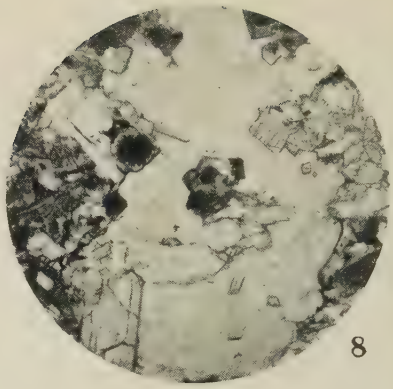
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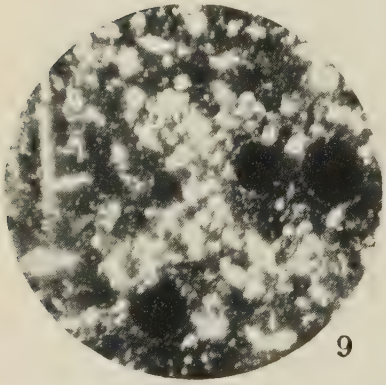
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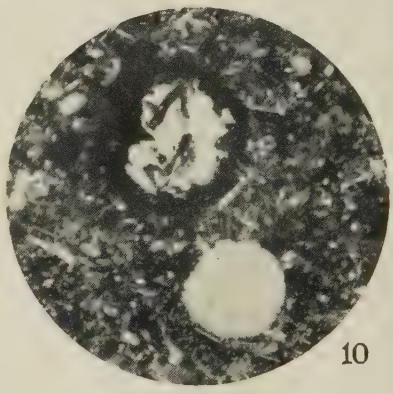
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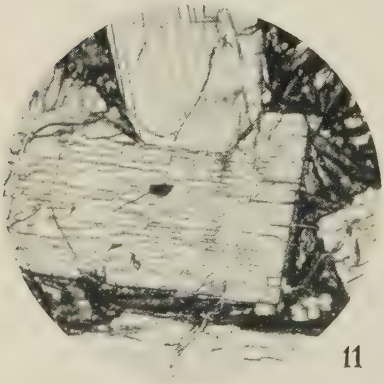
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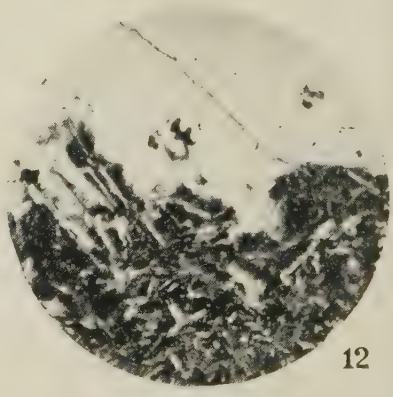
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W. F. P. McLintock: Metamorphic Rocks from Persia.

The spherulitic rhyolites of Jersey.

(With Plate XI.)

By A. E. Mourant, M.A., D.Phil.

[Read March 15, 1932.]

THE spherulitic rhyolites of Jersey show a development probably unequalled in the British Isles. They are particularly notable for the large size of the spherulites and for the variety of structures which they present. The object of the present paper is to describe some of these structures and to discuss their origin.

The first worker to publish a description of spherulitic rhyolites from Jersey was Davies (2).[1] Their field relations were described by Noury (4), while De Lapparent has discussed their petrology (5), (8) and the vexed question of their age (7). Parkinson (10), (12), (14) has given admirable and detailed accounts of the Bouley Bay rocks. A recent detailed survey of the Jersey volcanic rocks by the writer, details of which will be published elsewhere, shows the following sequence and approximate thicknesses:

3. Non-porphyritic rhyolite	...	1200 metres.
2. Porphyritic rhyolite	...	900 „
1. Andesite	...	600 „

Spherulites are mostly confined to the non-porphyritic series and they are best developed near the top of it.

The non-porphyritic rhyolite is a rock of felsitic texture; its colour is purplish-chocolate, or, less commonly, pale yellowish-green. It contains extremely rare and small phenocrysts of quartz and microperthite. An almost constant feature of the rock is the presence of strongly marked flow-banding, chiefly shown in the hand-specimen by alternate bands of different colours, evidently due to differences in the state of oxidation and perhaps in the abundance of iron present. The bands are usually about one millimetre thick.

Under the microscope the non-porphyritic rhyolite is seen to consist of finely granular orthoclase enclosed poikilitically by a patchy quartz

[1] Numbers in parentheses refer to the bibliography at the end of the paper.

mosaic (pl. XI, fig. 6). Hyndman and Bonney (9) have shown that the Bouley Bay rocks are soda-rhyolites, and it is thus evident that the orthoclase, here and probably throughout the series, is of a sodic variety.

The chief features which distinguish adjacent flow-bands in thin section are the relative abundance of sericite, a little of which is present in all the rhyolites, and the differing grain-size of the quartz and felspar. Along many of the bands elongated masses of quartz mosaic frequently occur, up to 1 mm. in thickness, evidently of late crystallization. The walls bounding these masses are usually lined with a fringe of earlier orthoclase or perthite. All these features are attributable to original irregular distribution of water. Variations in the state of the iron are more evident in the hand-specimen than in thin section. In a discussion of flow-banding Fuller (19) has suggested that the requisite differences in the condition of the iron might be produced by vapours penetrating a flow-breccia. Remelting and further flow would give the vari-coloured streaks. Rocks arrested in various stages of this process almost certainly occur in Jersey. This theory would, moreover, account for the differences in water-content.

The Spherulitic Rhyolites.—Small simple spherulites are common throughout the non-porphyritic rhyolite, but large spherulites and complex spherulitic growths are only known around Bouley Bay and in one small rock in St. Catherine's Bay.

The spherulites of Les Hurêts, overlooking the west side of Bouley Bay, have been described by Parkinson (10). In addition to simple spherulites up to about 1 cm. in diameter, there are found larger globular forms, only slightly complex, up to about 10 cm. Complex lenticular bodies, 5 to 20 cm. thick, merge into continuous bands with spherulitic structure and nodular outer surfaces. The total thickness of the spherulitic flow or flows at Les Hurêts is unknown, but a thickness of about 50 metres of lava is exposed without any obvious break. The different types and sizes of spherulites occur in separate bands parallel to the flow-banding, so that the rock looks in places like a bedded conglomerate.

Spherulites of several interesting types are found in a rock about 50 metres east of the south end of the long sea-wall of St. Catherine's Bay. Relatively simple bodies about 1 cm. in diameter occur locally, while complex lenticular spherulites, mostly from 5 to 20 cm. thick, are abundant throughout a thickness of about 10 metres of rhyolite.

The latter have in places coalesced into continuous sheets parallel to the flow-banding, similar to those at Les Hurêts. One such sheet was found to be over 30 cm. thick.

Petrology of the Spherulitic Rhyolites.—While studying the petrology of the spherulites the writer has been privileged to examine, in addition to material of his own collecting, a number of thin sections from Bouley Bay, kindly lent by Dr. Parkinson and mostly already described by him.

While superficially variable, the structure of the spherulites shows little fundamental variation. The primary spherulitic growth consists of radiating and more or less branching felspar fibres, often with a detectable negative elongation. Superimposed on these fibres is a patchy mosaic of quartz grains which enclose them poikilitically as the quartz does the granular felspar of the non-spherulitic varieties of rhyolite. The very small spherulites often consist of solid felspar but the larger ones show a complicated quartz mosaic, considerably influenced by the earlier felspar growth. The quartz grains are elongated in the radial direction, to which their optic axes are very roughly parallel. The quartz is, however, by no means as regularly arranged as the felspar.

Though the radial fibrous growth of the felspars is sometimes almost perfect, it is difficult to photograph or even to see in ordinary transmitted light. Pl. XI, fig. 3, shows the meeting of two spherulites in a specimen from Les Hurêts and is taken with oblique lighting from right and left: only those fibres which are nearly perpendicular to the plane of incidence are shown as illuminated. A few radial fibres of iron oxide[1] are seen as well as a quartz band (dark) representing a halt in the growth. Fig. 4 shows the same field as it appears under about the same magnification between crossed nicols. The polarization effects seen are almost entirely due to the patchy quartz. The parallelism of the quartz crystals is clearly far less perfect than that of the felspar, both as to external form and as to optical orientation. In this example the radial elongation of the quartz is much more pronounced than usual.

More nearly normal in the last respect are some small spherulites from St. Catherine's. In pl. XI, fig. 7, one of them is seen in ordinary

[1] Fibres of iron oxide are often found between those of felspar and appear, at first sight, to belong to the primary spherulitic growth. They are, in fact, probably a late development as they sometimes terminate against veins of secondary quartz.

transmitted light. The spherulite shows at its centre a more or less continuous growth of felspar, probably originally radial, though the radial structure is now chiefly shown by iron oxide. Farther out the felspar is in concentric bands suggestive of rhythmic growth. The felspar is set in 'patchy' quartz which is present nearly everywhere but is best seen between the dense felspar bands. Even in these, however, some felspar is present. A devitrified glass surrounds the spherulites and contains perlitic cracks, formed after the spherulites. Some of the small circles of the perlite are in turn occupied by bodies suggestive of rudimentary spherulites. The main spherulites are red with iron oxide. The perlite is green and finely granular with patches of a greenish-yellow micaceous mineral and with quartz forming a sort of disperse mosaic. In fig. 8 the poikilitic structure of a spherulite in this rock is seen between crossed nicols.

The 'patchy' or poikilitic structure, seen both in spherulites and in normal non-porphyritic rhyolite, seems, as suggested by Bonney and Parkinson (14), to be a combination of primary and secondary crystallization. The felspar, at least in the spherulites, is primary, while the quartz is of later growth and probably secondary. The rejection of iron oxide, in some examples, along nearly all the sutures of the quartz 'patches', shows almost beyond doubt that the silica first crystallized as quartz, since where tridymite is known to have occurred in the rhyolite each crystal has formed several differently orientated quartz crystals. 'Patchy' quartz has, however, formed in the near neighbourhood of original tridymite (now quartz but recognizable by its external form outlined in iron oxide). The tridymite is itself of late growth, yet, from the temperature relations of these minerals, it must be older than the quartz or the 'patches'. The latter is thus of very late formation.

Lenticular Spherulites and Spherulitic Bands.—There is little but a formal distinction between the large lenticular spherulites and the spherulitic bands which are clearly formed by their coalescence. Parkinson (10) has claimed that, at Les Hurêts, crystallization in them began at the edges and spread inwards.

An examination of the rocks in the field strongly suggested to the writer that both lenses and bands crystallized outwards from internal centres, and the slice represented in figs. 3 and 4 was cut from one of the bands at Les Hurêts to discriminate between the two possibilities. The upper part of the figures lies nearest the outside of the band: it is clear, from the way in which the two sets of fibres meet,

that recrystallization spread from the inside of the band. Dr. Parkinson has kindly lent the writer a thin section which at first sight seems to show inward growth. One part of the outer surface of the band is a concave curve with felspar fibres everywhere nearly perpendicular to it. Closer examination, however, shows that the fibres actually radiate from a large number of centres inside the band and meet in a similar manner to those of fig. 3.

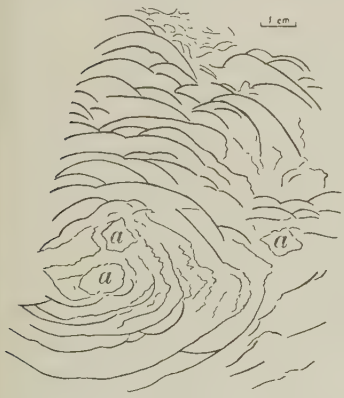

Fig. 1.

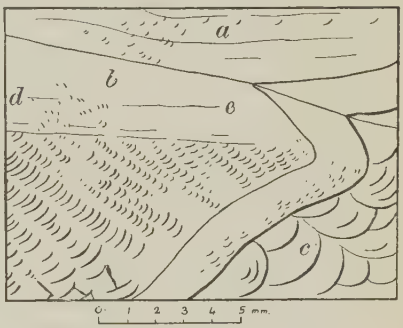

Fig. 2.

Fig. 1. Natural section across a complex lenticular spherulite from St. Catherine's Bay, showing lines of growth etched out by weathering. *a*, nuclear bodies.

Fig. 2. Natural section across a complex spherulite from St. Catherine's Bay. *a*, *b*, compact lenticular spherulites, *b* showing rhythmic structure. The quartz crescents are shown dark, as they appear in the hand-specimen. *c*, partial spherulites forming the outer part of a large complex body. *d*, *e*, flow-banding.

In the lenses and bands of St. Catherine's Bay the lines of growth have been weathered out in a rather striking manner. The large lenses originate either in a compact lenticular growth, occasionally rhythmic, or in an irregular but roughly spherical body suggestive of Parkinson's central bodies (10). Arranged as though piled up in all directions around this centre is a cluster of crescentic partial spherulites. Such an arrangement is shown in text-fig. 1 which represents the lines of growth weathered out on an exposed surface. The outside of each crescent is part of a single sphere, while its inner surface is moulded on those of a number of its neighbours. The outer simple surface is clearly that of free growth.

The growth lines in the lenticular spherulites where they coalesce

into a band show that crystallization started almost simultaneously at a number of points in a flow-plane. The main spherulite *b* of text-fig. 2 throws light on the origin of the central lenses. If we accept the little quartz crescents as growth-lines, while postponing consideration of the cause of their rhythmic arrangement, it is evident that crystallization spread outwards from any given point in the median plane except in so far as it was interrupted laterally by crystallization from other centres. Simultaneously a wave of nucleus formation was spreading in the plane.

It is not denied that crystallization in certain bodies can take place from without inwards but, as far as Jersey is concerned, the writer has only found it in fragments in breccias.

The median plane of a lenticular spherulite is often in a strongly marked flow-band of a pale colour, suggesting the presence of sericite, while secondary quartz is also visible at times and the iron is probably less highly oxidized than elsewhere. In accordance with the explanation adopted above, such bands are those that have been least acted upon in a flow-breccia and have thus retained their water and not been highly oxidized. This is in agreement with observations on a thin section of a loose pebble from St. Catherine's Bay, consisting of a very fine grained breccia remelted and partly drawn out. Those lenticular streaks which are most vesicular are also most highly spherulitic. Iddings (3) and Parkinson (12) have agreed that the production of spherulites is favoured by the presence of water.

Rhythmic Phenomena.—Comment has already been made on the rhythmic alternation of spherulitic felspar and 'patchy' quartz in the small spherulites at St. Catherine's. Parkinson (12) has described a further development of this structure at Les Hurêts in which the felspar zones alternate with bands of pure quartz, but much more striking examples of rhythmic structure occur in St. Catherine's Bay. The structure is not common but seems to appear anywhere at random in the spherulitic part of the flow and in almost any part of the large complex bodies, though generally in the more compact central lenticular spherulites.

The lenticular spherulites are sensibly symmetrical about flow-planes but the rhythmic structure is sometimes found only on one side of an otherwise symmetrical body. Cases of perfectly symmetrical rhythmic bodies do occur, and asymmetry is probably mainly an accidental result of the rarity of rhythmic structure. The asymmetry does, however, at times seem to be systematic, as in the case illustrated

in text-fig. 2, which represents part of one face of a hand-specimen. The main spherulite is almost symmetrical except that rhythmic trains of alternating quartz and felspar arcs only arise from one side of the median flow-streak.

The structure of a rhythmic lenticular spherulite from St. Catherine's as seen in thin section is shown in pl. XI, fig. 9. It is very evenly developed and extends with something like regularity through a large part of a spherulite some 15 cm. thick. The cloudy granular areas in the figure represent felspar together with a little quartz and some finely divided iron oxide; the white areas are clear quartz. The felspar is arranged in parallel or slightly diverging piles of arcs, capping one another and separated by quartz. The arcs are about 0·4 mm. long and the distance from the inside of one to that of the next is about 0·14 mm. The concave side of each felspar arc is sharp, while on the outside it is ragged with needles running out into the quartz area. This is a very constant feature where quartz bands occur in spherulites, whether rhythmic or not, and shows that a given phase of felspar crystallization began sharply but died out gradually.

Iddings (3) has described and figured examples of rhythmic spherulites but none of his cases approach the best Jersey ones in delicacy. More nearly similar to the latter is a structure figured by Delesse (1, pl. 2, fig. 6) but dismissed in a few lines of description.

The arcs of felspar (cloudy in most of the figures) are usually separated by homogeneous quartz resembling vein-quartz. In a rhythmic spherulite from the cliffs north of Les Hurêts (fig. 5), however, we find that the larger spaces between the felspar arcs show late crystallization on the walls—first felspar, then tridymite, now seen as quartz outlined in iron oxide. Upon this grew a thin coating of quartz or more tridymite and the cavity was then filled with yellowish sericite, occasionally followed by more quartz.

This, allowing for the alteration of the Jersey examples, is approximately the order of crystallization in the cavities in the spherulites at Obsidian Cliff, Yellowstone National Park. In the latter case Iddings (3) has supposed that in the process of crystallization, rhythmic or otherwise, the water present in the lava first separated as vapour and later condensed and promoted the recrystallization of the confining walls.

The establishment of the Reaction Principle has, however, drawn attention to the frequency with which equilibrium is shifted with fall

of temperature in a crystallizing magma so that recrystallization of earlier formed minerals takes place. Such a recrystallization seems to have taken place in the Jersey rock last described: it is unnecessary to assume, as Iddings does, that water was temporarily restrained from activity by removal to another phase—especially since cases are found where there is no clear quartz but merely increase and decrease in the proportion of felspar (fig. 7).

Of course the original lava did contain water, but it seems rather that when the primary felspar crystallized there was left a liquid consisting mainly of water and silica with perhaps a little felspathic material. Such a liquid would be much more mobile than the lava, while yet probably being miscible with and grading into it. On the other hand, it would readily produce the observed effects of crystallization in a cavity.

The Mechanism of Rhythmic Recrystallization.—The regularly repeated felspar arcs are similar to Liesegang rings and some similarity probably exists between their modes of formation, though there is no question of diffusion of a reagent producing double decomposition in the rhyolite. Liesegang rings are, in the typical case, regularly spaced concentric circles of silver chromate produced when a drop of silver nitrate solution is placed upon a film of moist gelatine containing a soluble chromate. Wilhelm Ostwald (13) explained their production by supposing that the precipitate did not crystallize out the moment the solution was saturated but when it reached the supersolubility point (metastabile Grenze). The whole neighbourhood was then depleted of chromate down to the normal solubility, with the result that the precipitant had to diffuse some distance beyond the first precipitate before it could again raise the concentration of the precipitate to the supersolubility point and produce another ring of the substance.

The supersolubility point is a well-defined phenomenon, thoroughly investigated by Miers and Isaac (15). Miers (16) has used it, on the same lines as Wilhelm Ostwald, to explain the rhythmic crystallization of potassium dichromate from aqueous solution. The later theories regarding rhythmic precipitation of Wolfgang Ostwald (18) and of Bradford (17) are more complicated and only apply to cases of double decomposition: they do not concern us here directly. Hedges (20), in a masterly survey of the whole subject, reaches a conclusion which embraces Wilhelm Ostwald's theory but is of more general application. He considers that 'the essential condition for

periodicity appears to be the existence of some critical condition determining a change which proceeds to completeness once the critical value is reached'.

Several previous theories of the development of rhythmic spherulites demand consideration.

Cross (6) supposed that most of the structures seen in spherulites were the result of forms taken up by amorphous silica (opal). Most of the facts adduced in the present paper, however, point to felspar as the primary builder of structures.

Iddings (11) held that pulsating crystallization was due to 'the lowering of the saturation of the surrounding mother-liquor caused by the sudden liberation of heat in the act of crystallization and to the rapid extraction of crystallizing molecules'. This theory is practically the same as that of Wilhelm Ostwald and is, with important modifications, adopted by the writer.

Parkinson (12) holds that the latent heat, if any, of felspar is probably inadequate for the process suggested by Iddings. The crystallization of felspar from the lava on cooling, however, proves that its latent heat of solution in the lava is negative. However small it may be, conditions will almost certainly occur from time to time under which the liberation of heat on crystallization will more than balance, for the requisite short time, the loss of heat due to cooling. Parkinson himself seems to hold that rhythmic interruption of crystallization was produced mechanically by the accumulation of water-vapour set free simultaneously with the felspar. As already mentioned, there can have been no liberation of vapour in the small spherulites at St. Catherine's (fig. 7), and even where clear quartz occurs between the felspar arcs the sharp onset and gradual ending of crystallization are more suggestive of a physico-chemical mechanism on the lines suggested by Wilhelm Ostwald. The exact nature of such a mechanism must next be considered.

Simple spherulites might well grow rapidly from a highly supercooled lava without reference to the direction in which heat was being lost. Rhythmic growth, on the other hand, implies a continual oscillation at the growing front between the stable and labile states; so that loss of heat will closely control the process.

The rhythmic growth of a complex spherulite symmetrically about a plane would at first sight appear to demand the conduction of heat from both sides towards the plane and its removal or annihilation on arriving there. This is impossible, and we must therefore look for a

subsidiary controlling influence. The dominance of the direction of the thermal gradient will be mitigated by slow cooling. Assuming that cooling was very slow, let us consider the history of a fairly large mass of lava of sensibly uniform temperature at the supersolubility limit for felspar.

Owing to some slight chemical peculiarity of a particular flow-plane (a purely physical peculiarity would hardly be sufficiently persistent) spherulitic crystallization begins almost simultaneously from a number of points in it. Crystallization will continue until the concentration of felspar in the immediately surrounding liquid is reduced to the normal solubility value. This crystallization will have liberated a certain amount of latent heat, and before our mass of lava can again crystallize spontaneously this heat must be conducted away. Once interrupted, there now seems to be no reason why crystallization should continue about the former centres. We should rather expect it to start from points distributed almost at random throughout the mass; and this is probably what does happen in many cases.

Accepting current theories of rhythmic crystallization, we can hardly avoid the conclusion that symmetrical rhythmic spherulitic growth can only take place in the body of a lava, as we see it to have done, if each pulse of crystallization gives rise to an agent which promotes nucleus formation in the succeeding zone. If we search for such an agent we immediately note one peculiarity in the zone surrounding the spherulites already formed. Water, which is a highly mobile mineralizing agent, has been liberated, and will undoubtedly diffuse outwards. It may now be assumed that, while the rest of the mass can remain in the labile state with some chance of immunity from crystallization, the presence of water promotes nucleus formation in the zone surrounding the spherulites. If this be granted we have the requisite conditions for rhythmic growth.

The simultaneous production of major growth-lines in adjacent spherulites (text-fig. 2) agrees well with the almost perfect uniformity of temperature at a given time, assumed above. On the other hand, the conditions assumed clearly represent an ideal case, and if they could hold at all it is almost certain that the lava remote from crystals and liberated water sometimes fell not merely slightly but considerably below the supersaturation point without crystallizing. It is also probable that, even near the growing spherulite, nuclei sometimes failed to arise immediately the same point was reached. By adopting this further hypothesis, which allows the existence of slight

local temperature gradients, we can account for most of the irregularities observed in actual rocks, such as the interpolation of a quartz band along part only of the growing front.

The asymmetrical growth shown in text-fig. 2 is perhaps due to the migration of water, or water and silica, along a temperature gradient, or perhaps to bands originally of different composition. It is not so easy to account for the solid masses of felspar along the junctions of the separate systems. In most cases of the meeting of systems of rhythmic crystallization from two centres the lines of junction are marked by clear spaces as demanded by the simple theory. It is possible that in the rhyolite the mobile silica solution segregated somewhat, after the felspar crystals were formed. This particular fact regarding the distribution is more readily explained by Parkinson's theory (p. 235).

In spite of these points the theory here put forward is, of those yet suggested, the one to which the objections have the least appearance of being fundamental.

I should like to express my thanks for valuable help and criticism to Prof. H. L. Bowman, Mr. R. Brooks, Dr. A. Harker, Mr. W. E. Mourant, Prof. W. J. Sollas, Mr. R. C. Spiller, Dr. H. H. Thomas, and Dr. A. K. Wells, also to Dr. J. Parkinson for the loan of thin sections.

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Explanation of Plate XI.

Thin sections of spherulitic rhyolites from Jersey.

Fig. 3. The meeting of two simple spherulites in a spherulitic band at Les Hurêts. Oblique lighting. ×23.

Fig. 4. The same field as fig. 3. Crossed nicols. ×26.

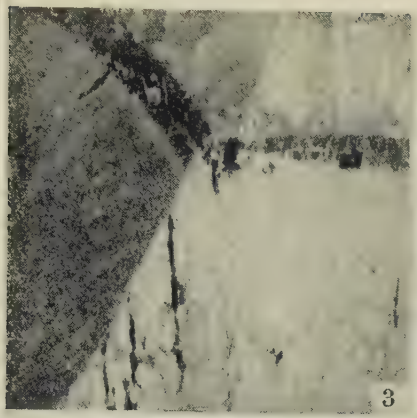
Fig. 5. Crystallization in the spaces between the felspar arcs of a rhythmic spherulite from the sea-cliff north of Les Hurêts. Ordinary light. ×23.

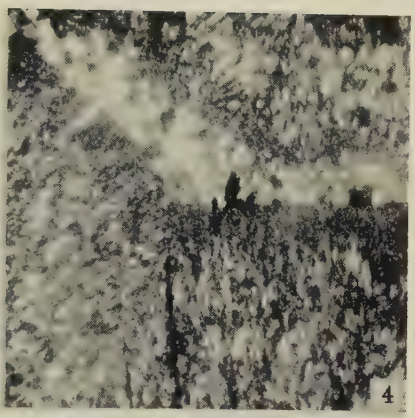
Fig. 6. Poikilitic structure in non-porphyritic rhyolite, Le Quesne's Quarry, La Crête, St. Martin. Crossed nicols. ×69.

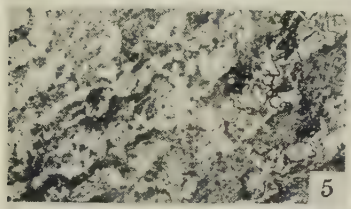
Fig. 7. Small rhythmic spherulite in perlitic rhyolite, St. Catherine's Bay. Ordinary light. ×23.

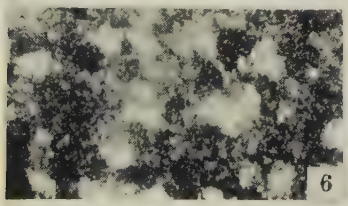
Fig. 8. Small spherulite, St. Catherine's Bay (same slide as fig. 7). Crossed nicols. ×67·5.

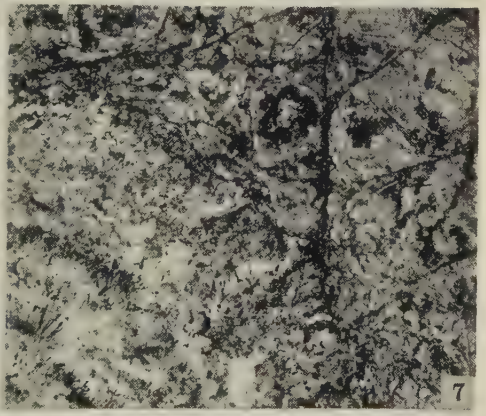
Fig. 9. Complex rhythmic spherulite, St. Catherine's Bay. The grey areas represent felspar with some quartz and iron oxide. The white areas are quartz. Ordinary light. ×23.

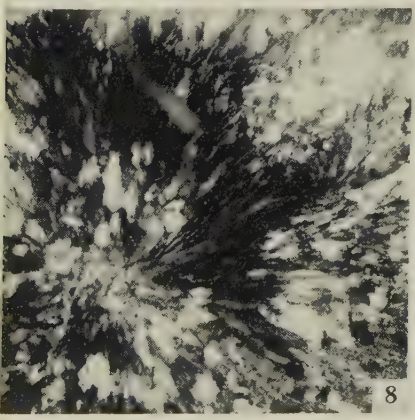


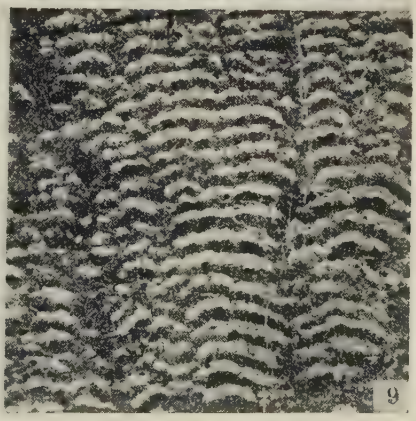












A. E. Mourant: Spherulitic Rhyolites of Jersey.

An albitite from Ve Skerries, Shetland Isles.

By Frederick Walker, M.A., D.Sc.
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[Read March 15, 1932.]

THE Ve Skerries form a small group of rocks situated just over three miles WNW. of Papa Stour on the west coast of the Shetland Isles. Owing to the notoriously troubled state of the surrounding waters a landing can only rarely be effected on them, and it is not, therefore, surprising that no account of their geology has yet appeared. Through the kindness of Mr. J. Glencorse Wakelin, Secretary to the Northern Lights Commissioners, the writer has been able to examine a large specimen of the constituent rock secured by Mr. Wakelin in 1930, and considered by him to be typical of the group. The results of this examination proved to be of considerable interest and are given below.

In the hand-specimen the rock is seen to be of even texture and medium grain. It is white in colour but is relieved by a few dark-green or black spots and by very thin veins of haematite. In appearance it is not unlike an aplogranite, but examination under a hand-lens reveals the absence of quartz, while much of the felspar is seen to be twinned on the albite-law.

Under the microscope it is at once apparent that acid plagioclase is the dominant mineral of the rock, the percentage being well over 90 in every section examined. It occurs as irregular crystals whose junctions interlock so intricately that in many cases small inclusions of acid plagioclase in large crystals of the same mineral may be observed. The crystals average about 1 mm. across and do not show much variation in size. They are all twinned on the albite-law with the lamellae usually thin and numerous; Carlsbad and pericline twinning are comparatively rare. The mineral is optically positive, the symmetrical extinction-angle measured on the albite lamellae is 14°, and the mean refractive index determined by the immersion method is $1{\cdot}530 \pm 0{\cdot}002$. It is evident, therefore, that the plagioclase is an almost pure albite. The crystals are usually quite fresh, though slight turbidity may sometimes occur and the cleavage cracks

are often accentuated by the deposition of dark minerals. No signs of zoning were seen, nor was any felspar other than albite detected in the rock. Quartz is either very sparingly represented by small crystals or is completely absent.

The green spots visible in the hand-specimen prove under the microscope to be chlorite formed by the decomposition of a ferro-

Fig. 1. Albitite, Ve Skerries, Shetland Isles. Crossed nicols. ×100.

A large crystal of albite showing well-marked lamellar twinning occupies the top of the field. The lower part of the field is made up of smaller crystals of albite showing only traces of twinning and having highly irregular boundaries.

magnesian mineral. This chlorite occurs in patches up to 0·8 mm. across, which, by their habit, probably represent aggregates of biotite flakes. It is green in colour, is distinctly pleochroic, and individual members of the aggregates show straight extinction. The proportion of the mineral does not exceed 2 %.

Magnetite occurs in slightly less amount, forming small crystals of irregular shape up to 0·4 mm. across. These are evidently of early crystallization and are sometimes associated with a little brownish-grey sphene which may possibly indicate that they are titaniferous.

Apatite is a sporadic accessory forming needles with a maximum diameter of 0·15 mm., while small crystals of zircon are exceedingly rare.

The rock is plainly an example of the rare alkaline type albitite and, as its texture is typically granitoid, it is probably plutonic. Except for occasional slight flexuring and rarer fractures in the albite lamellae there are no signs of crushing. Part of the specimen was analysed by Dr. Naima Sahlbom and the results are given below together with the norm, specific gravity, and analyses of similar rocks for comparative purposes.

	A.	B.	C.	D.	E.
SiO_2 ...	66·56	67·07	66·54	66·85	66·62
TiO_2 ...	0·16	0·23	—	—	—
Al_2O_3 ...	19·41	18·85	—	20·11	17·56
Fe_2O_3 ...	1·53	0·91	—	—	—
FeO ...	0·22	n.d.	—	1·43	1·87
MnO ...	trace	—	—	—	—
MgO ...	0·32	1·53	0·77	0·31	0·38
CaO ...	0·68	1·09	0·43	1·03	0·73
Na_2O ...	10·64	10·84	10·28	9·70	10·09
K_2O ...	0·34	0·48	0·89	0·44	1·83
H_2O+ ...	0·20	n.d.	—	0·33	0·73
H_2O- ...	0·14		—		
P_2O_5 ...	0·16	—	—	—	—
	100·36	101·00	—	100·20	99·81
Sp. gr. ...	2·64	—	—	—	—

Norm of A.	
Quartz ...	2·0
Orthoclase ...	1·7
Albite ...	90·1
Anorthite ...	2·5
Corundum ...	0·6
Enstatite ...	0·8
Ilmenite ...	0·3
Magnetite ...	0·2
Haematite ...	1·3
Apatite ...	0·3
H_2O	0·3

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C. Albitite, Plumas Co., Sierra Nevada, California. Partial analysis by W. F. Hillebrand. U.S. Geol. Survey, 14th Ann. Rep., 1894, pt. 2, p. 477.

D. Albite-porphyry (matrix), Meall à Bràghaid, Sutherland. Analyst, M. F. Heddle. Min. Mag., 1884, vol. 5, p. 141.

E. Do., phenocryst. The same.

Age and Affinities.—Analyses A, B, and C bring out the close chemical resemblance of the Ve Skerries albitite to similar rocks from the Ural Mountains and the Sierra Nevada which occur as dikes intrusive into diorite and serpentine respectively. More important, however, is the equally strong resemblance of the Ve Skerries rock to the albite-porphyry of Meall à Bràghaid in the Assynt district of Sutherland described by Heddle.[1]

Unfortunately, no information is available as to the mode of occurrence of the Ve Skerries albitite, but it seems most probable that it is to be referred either to the igneous activity prevalent in the

[1] M. F. Heddle, Min. Mag., 1884, vol. 5, p. 141.

neighbouring portions of the Shetland Islands during Lower Old Red Sandstone times,[1] or to the earlier post-Cambrian activity represented by the alkaline plutonic masses of Assynt and Ben Loyal.[2] The Shetland rocks are certainly of calcic facies in the main, but Dr. F. C. Phillips[3] has described riebeckite-bearing dikes cutting the granite of Ronas and referred by him to the latest phase of igneous activity in the district. He also demonstrates by a chemical analysis the alkaline character of the adjacent granite. Both these types, however, contain a large percentage of potash, and there is no record of any highly sodic rock in this district. The rhyolite of Papa Stour, only three miles distant from Ve Skerries, is an orthoclase-bearing type.

The Meall à Bràghaid rock described by Heddle is probably from the large sill intruded between the Torridonian and the basal Cambrian quartzite on that mountain. It is undoubtedly one of the minor intrusions associated with the plutonic activity of the Assynt district, and is actually less than a mile from the perthosite facies of the Loch Ailsh mass described by Dr. J. Phemister.[4] Professor H. H. Read[5] has recently shown that the Ben Loyal mass belongs to this period of activity, and although the Shetland Islands lie far to the north there is no reason why the Ve Skerries rock may not also be of the same age. The Assynt sill is certainly the only other example of albitite yet recorded in Britain, but when a systematic survey of the minor intrusions associated with this period of activity is undertaken, many more may be discovered.

The possibility of a Tertiary age for the Ve Skerries rock must not be excluded, and in this connexion the case of the highly sodic Rockall granite is, perhaps, suggestive,[6] but the meagre available evidence seems to link it most closely with the post-Cambrian activity of Assynt.

Acknowledgements.—The author is greatly indebted to Mr. J. Glencorse Wakelin for providing him with the material examined, and to the Carnegie Trust for the Universities of Scotland for a grant which enabled him to have a chemical analysis made.

[1] T. M. Finlay, Trans. Roy. Soc. Edinburgh, 1930, vol. 56, pp. 676–693.

[2] Mem. Geol. Survey, Central Sutherland, 1931, p. 178.

[3] F. C. Phillips, Geol. Mag., 1926, vol. 63, pp. 72–77.

[4] J. Phemister, Mem. Geol. Survey, Strath Oykell and Lower Loch Shin, 1926, p. 44.

[5] H. H. Read, Mem. Geol. Survey, Central Sutherland, 1931, p. 178.

[6] G. W. Tyrrell, Geol. Mag., 1924, vol. 61, pp. 19–25.

Studies on the zeolites. Part III. Natrolite and metanatrolite.[1]

By Max H. Hey, B.A., B.Sc.

With X-ray measurements by F. A. Bannister, M.A.

Assistant-Keepers in the Mineral Department of the British Museum of Natural History.

[Read January 19, 1932.]

Introductory.

ONE of the most typical occurrences of natrolite, in the Puy-de-Dôme amygdaloids, formed the main type occurrence of R. J. Haüy's species Mesotype (1801); but when A. F. Gehlen and J. N. Fuchs (1813) and J. N. Fuchs (1816) recognized the individuality of soda-, lime-, and lime-soda-mesotypes, and divided Haüy's species into three, they discarded Haüy's name altogether, using for the three new species the names natrolite, scolecite, and mesolite. Natrolite was not a new name, having been given in 1803 by M. H. Klaproth to the well-known yellow-banded fibrous-radiating zeolite from Württemberg. The name mesotype has persisted for the whole group (in which sense it will be used here); and for long the names soda-, lime-, and lime-soda-mesotype were used as well as Gehlen and Fuchs's names. In France, however, the name mesotype is used in a more restricted sense for natrolite only.

The individuality of natrolite, mesolite, and scolecite, and especially of mesolite, has been repeatedly doubted, but the accumulated observations of Sir David Brewster,[2] P. Reiss and G. Rose (1843), A. Des Cloizeaux (1857), R. Görgey,[3] H. L. Bowman,[4] A. Cavinato (1927), and others leave no doubt that the mesotype group is not a single isomorphous series, but three distinct and separate species, with a limited degree of isomorphous replacement. This conclusion is fully supported by the present work.

[1] Part II, Min. Mag., 1932, vol. 23, p. 51.

[2] Sir D. Brewster, quoted in F. Mohs, Min., 1825, vol. 2, p. 237.

[3] R. Görgey, Tschermaks Min. Petr. Mitt., 1908, vol. 27, p. 255; 1909, vol. 28, p. 79.

[4] H. L. Bowman, Min. Mag., 1908, vol. 15, p. 216.

Several varieties of natrolite have been distinguished, and a number of supposed species have proved on further study to be merely natrolite. Thus *Högauite* (C. J. Selb, 1803) is a synonym for natrolite from Högau, the original Württemberg locality described by Klaproth.

The name *Bergmannite* (C. F. Schumacher, 1801) was applied to the pseudomorphs of natrolite, or natrolite and diaspore, after nepheline (and possibly other minerals), common in the Langesundfjord district of Norway. *Spreustein* (A. G. Werner, 1811) and *Radiolite* (H. M. T. Esmark, 1828) are similar impure occurrences,[1] in part at least pseudomorphous, while *Brevicite* (J. Berzelius, 1834) is a much purer, but still impure material; all these are from the same district. From this region also comes *Eisen-Natrolith* (C. Bergemann, 1851), which W. C. Brøgger (1889) showed to be ordinary natrolite coloured green by inclusions. These inclusions Brøgger believed to be chloritic, possibly allied to stilpnomelane, but if all the aluminium of Bergemann's analysis is set down as natrolite, the residue after deduction of the natrolite approaches an aegirine-augite in composition.

Lehuntite of T. Thomson (1836) is shown by an analysis by J. Apjohn (1845) to be merely a compact natrolite. Many specimens carry a good deal of extra, occluded water. *Savite* of G. Meneghini and E. Bechi (1852) was shown by Q. Sella (1858) and by A. Des Cloizeaux (1867) to be natrolite; the impurity in Bechi's material has generally been supposed to be serpentine, but his analysis rather suggests enstatite.

Galactite (W. Haidinger, 1855)[2] is a milky-white variety of natrolite. The cause of its opacity is not known; some authors have supposed it to be due to a replacement of soda by lime, but several of M. F. Heddle's analyses (1856) of galactites show only small amounts of lime, less than have been found by the author and others in glassy natrolites unquestionably free from mesolite or other impurity. *Fargite* (M. F. Heddle, 1856) is a red variety of natrolite (coloured by iron) from Glen Farg, Perthshire. If Heddle's material was quite free from mesolite (which also occurs in Glen Farg), this must

[1] Some spreusteins, however, consist mainly of the doubtful zeolite hydronephelite, which many authors hold to be a mixture of natrolite and diaspore; the author hopes to start a re-investigation of hydronephelite shortly.

[2] The name was certainly given by Haidinger before 1847, as it is mentioned by E. F. Glocker, Synopsis Min. (Halle), 1847, p. 176. This appears to be the first publication of the name.

be one of the most lime-rich natrolites ever analysed, 30 % of the soda being replaced by lime.

Mooraboolite of G. B. Pritchard (1901), from Maude, Moorabool valley, Victoria, was shown by L. J. Spencer (1903) to be merely impure natrolite.

Epinatrolite of S. J. Thugutt (1911) was distinguished from natrolite solely by differences in the intensity of the stain it takes on application of methylene blue or of silver nitrate followed by potassium chromate, after it has been ignited for short periods.[1] This does not seem to the author sufficient ground for the establishment of a new species, and a re-investigation of the substance is called for, especially by X-ray and vapour-pressure methods. Unfortunately the author had no material available to carry this out.

Composition.

All the available analytical data, including nine new analyses by the author (table I), indicate that, unlike thomsonite, natrolite is a zeolite of fixed Si/Al-ratio, namely 1·5. In common with the other true zeolites, the ratio O/(Si + Al) is 2, indicating an indefinitely extended, non-polar bonded anionic framework. The X-ray data indicate a unit cell containing 80 oxygen atoms, 16 aluminium, and 24 silicon atoms, and the water content is also appreciably constant at 16 molecules per unit cell. The normal characteristic number of kations is 16, and occurrences in which 16 sodium atoms per unit cell form the only kationic content are not uncommon. But frequently a part of the sodium (up to 1·0 atom per unit cell[2]) is replaced by potassium, and the author's analyses tend to suggest that an appreciable replacement of this kind is more common than has been generally realized, many analysts not having troubled to separate the alkalis. A limited degree of replacement of two sodium atoms by one calcium atom may also occur, up to perhaps two atoms Ca per unit cell (replacing four atoms Na), but the precise limit to this replacement cannot be fixed, since so few analyses have been made on material of optically controlled purity. In two of the author's analyses, the natrolite was intimately associated with mesolite in the

[1] Thugutt has recently (1932) stated that there is a difference in the birefringence. It is, however, too small to be reliably measurable.

[2] The analysis by S. von Waltershausen (1853) showing 2·40 atoms K per unit cell is probably in error. The 20·35 % potash in C. G. Gmelin's analysis (1850) is clearly a misprint for 0·35 %.

one case, and calcite in the other (nos. 9 and 3 of table I respectively); these might be hoped to give some indication of the limit of replacement, but the analyses are not as satisfactory as could be wished. In the first, the amount of material available was very small, while in the second, the natrolite and calcite were so intimately intergrown that a complete separation was impossible, and the composition of the natrolite had to be arrived at by deduction of the calcite found. Even allowing for these sources of error, however, the difference between the two calcium contents is remarkably great. Probably the limit of replacement varies with temperature and other conditions.

TABLE I. New chemical data for natrolite.

		1.	2.	3.	4.	5.	6.	7.	8.	9.
Percentage composition.	SiO_2 ...	47·60	47·38	46·52	47·33	47·15	47·29	46·96	47·22	47·1
	Al_2O_3	27·40	27·63	26·29	27·67	27·39	27·56	27·12	26·94	27·8
	Na_2O	15·36	14·96	10·56	14·74	15·27	14·63	12·48	14·45	15·9
	K_2O ...	0·23	0·41	0·46	0·50	0·50	0·59	1·25	1·27	—
	CaO ...	0·13	0·54	3·14	0·22	0·30	0·80	1·89	1·05	1·3
	H_2O ...	9·47	9·58	9·63	9·64	9·53	9·40	10·80	9·28	9·35
	Total	100·19	100·50	100·51*	100·10	100·14	100·27	100·50	100·21	101·4
Oxygen % ...		42·21	42·31	42·32	42·14	42·06	42·17	41·54	41·99	42·09
Oxygen, atoms per unit cell		80·94	80·94	80·90	80·91	80·83	81·01	79·41	80·52	—
Atoms per unit cell, assuming oxygen 80.	Si ...	23·97	23·84	24·26	23·90	23·84	23·84	23·95	23·92	23·5
	Al ...	16·24	16·38	16·16	16·36	16·32	16·51	16·28	16·10	16·4
	Na ...	14·99	14·59	10·67	14·43	14·96	14·29	12·34	14·29	15·4
	K ...	0·15	0·26	0·29	0·33	0·33	0·37	0·82	0·82	—
	Ca ...	0·08	0·29	1·76	0·11	0·18	0·43	1·04	0·53	0·7
	H_2O ...	15·91	16·08	16·74	16·23	16·07	15·80	18·38	15·68	15·6
Specific gravity		2·245	2·245	2·238	2·248	2·250	2·249	2·238	2·245	—

1. B.M.39877. Puy de Marmant, Puy-de-Dôme, France. Clear stout prisms.
2. B.M.49545. Salesl, Leitmeritz, Bohemia. Crust of small clear prisms.
3. B.M.1925,489. Moore, Trenton, New Jersey. Glassy needles with calcite.
4. Benallt manganese mine, Rhiw, Carnarvonshire. Large translucent crystals.
5. B.M.52571. Cape Blomidon, King's Co., Nova Scotia. Clear crystals.
6. B.M.62763. De Beers diamond mine, Kimberley, S. Africa. Clear crystals.
7. B.M.1914,944. Seiser Alpe, Bozen, Tyrol. Radiating massive.
8. B.M.1914,769. Snake Hill, North Bergen, New Jersey. Clear crystals.
9. B.M.62354. Neubauerberg, Mickenhan, Böhmisch-Leipa. Long, hair-fine needles, each with a very thin cap of mesolite.

* Including 3·91 % $CaCO_3$.

A collection was made of all the available analyses of natrolite, and the results, recalculated in atoms per unit cell of 80 oxygen

atoms, classified as was done for thomsonite. A survey of the whole of these data leads to the conclusions above set out; there is no evidence that the calcium content is due, or even partially due, to a substitution of the type NaSi⇌CaAl, nor is there any evidence that the water content increases with increase of lime content, as has

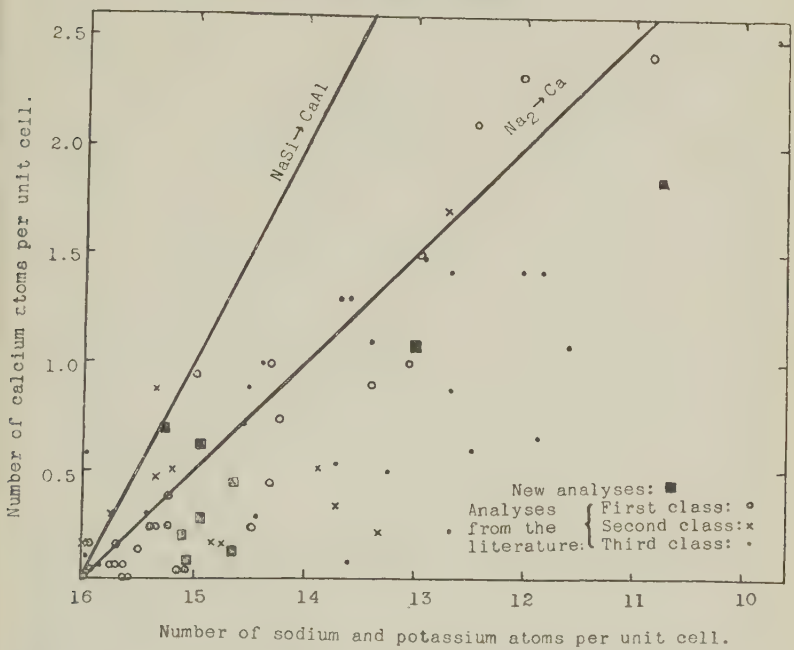

FIG. 1. A graphical representation of such analytical data for natrolite as take account of the lime content, to show that calcium replaces sodium in the proportion $Na_2 \rightarrow Ca$, and cannot be accounted for by a replacement of type NaSi→CaAl.

been occasionally supposed. It seems unnecessary to give the actual recalculated figures here,[1] but fig. 1, in which the calcium content (for those analyses which take account of a possible calcium content) is plotted against the sum of the alkalis, presents the evidence for a $Na_2 \rightarrow Ca$ rather than a NaSi→CaAl substitution.

[1] 119 analyses were collected from the literature (see bibliography, p. 284), of which 45 were accounted as first-class, 23 second-class, 34 third-class, and 14 rejected as worthless. Of the first-class analyses, lime was estimated or shown to be absent in 30, potash in 15, and both in 11. The corresponding figures for the second-class analyses are 14, 10, and 8, and for the third-class, 24, 6, and 5.

Crystallography, density, pyroelectricity, and X-ray work.

Natrolite was originally believed by R. J. Haüy (1801) to be tetragonal, but was soon found to be really orthorhombic. O. Luedecke (1881), W. C. Brøgger (1889), and others brought forward evidence for the existence of monoclinic natrolites, but other workers, including the author, can find no confirmation of these results (cf. below, under optics).

A considerable number of goniometric measurements have been made on natrolite, the fullest being those of W. C. Brøgger (1879, 1889), who found an axial ratio of 0·9785 : 1 : 0·3536 ; but as G. Kalb (1930) points out, natrolite is very prone to the development of vicinal faces, and since the symmetry is fairly low, special precaution is necessary to obtain a reliable axial ratio. The cleavage angle, which will not be affected by vicinal development, has been measured by Dr. L. J. Spencer on the crystals from Benallt described below, and by W. C. Brøgger (1879) on crystals from Stokö, Langesundfjord, the angles found being 88° 55½′ and 88° 51′ respectively. Taking the mean, 88° 53′, the axial ratio $a:b$ becomes 0·9807. From this and the values 36° 44′, 37° 35′, and 53° 35′ deduced by Kalb as the most probable values for the true angles $(111):(1\bar{1}1)$, $(111):(\bar{1}11)$, and $(111):(\bar{1}\bar{1}1)$, three values for the axial ratio $c:b$ may be calculated; the three agree closely, and the axial ratio may be safely taken as very nearly $a:b:c = 0{\cdot}9807 : 1 : 0{\cdot}3537$. This is in good agreement with the value obtained from Mr. F. A. Bannister's X-ray measurements of the cell-sides, which give $a:b:c = 0{\cdot}981 : 1 : 0{\cdot}354$, and will be adopted throughout the present work. The X-ray measurements of A. L. Parsons (1930), L. Pauling (1930), F. Halla and E. Mehl (1930), and J. Wyart (1931) differ considerably among themselves, and agree none too well with the above ratio, leading to axial ratios of 0·9785 : 1 : 0·3572, 0·9769 : 1 : 0·3534, 0·9823 : 1 : 0·3544, and 0·9865 : 1 : 0·3551 respectively.

The normal habit of natrolite is the simple combination m (110), o (111), as long needles parallel to the c-axis. Sometimes a (100) and b (010) are developed, and less often pyramids z (331) and π (551) and domes D (101) and e (011); other forms are decidedly rare. The natrolite of abnormal habit, elongated parallel to the b-axis, described by V. von Lang (1863) from the Langesundfjord district, Norway, and figured in most text-books (e.g. Dana, Syst. Min., 6th edn., 1892, p. 600, fig. 3), has been shown by the

author[1] to have been thomsonite. Twins of natrolite have been described with twin-planes: (110), by C. Stadtländer (1885), from Stempelberg, Marburg, and by A. Lacroix (1896) from several localities; (011), by G. Cesàro (1909), from Hohentwiel; and (031), by V. von Lang (1863), from the Langesundfjord region.

Of ten natrolite specimens measured by the author, on the three-circle goniometer, seven show the simple combination *m* (110), *o* (111) (or rather, one vicinal form near *m* and three near *o*); two, from Jakuben, Bohemia, and De Beers diamond mine, Kimberley, show also the forms *a* (100) and *b* (010); and the tenth, from the Benallt manganese mine, Carnarvonshire, has a more complex habit. The measurements on the first nine are given in table II.

TABLE II. Goniometric measurements on natrolite.

	1.	2.	5.	6.	8.	10.	11.	12.	13.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
am	—	43 39	44 36	44 35	42 38	44 27	44 39	44 29	44 29
cv_1	26 50	25 38*	26 42	26 43	26 46	26 46	26 47	26 42	26 32
cv_2	28 36	—	27 25	27 39	27 6	27 55	27 16	27 39	26 45
cv_3	25 47	—	25 35	26 13	25 57	26 5	25 52	26 19	—
$[ca]:[cv_1]$ ...	44 29	44 22*	44 0	44 38	43 50	44 50	45 2	45 27	43 25
$[ca]:[cv_2]$ ...	41 47	—	44 12	44 40	41 20	44 34	45 39	43 13	44 20
$[ca]:[cv_3]$ ...	41 34	—	36 11	42 39	40 54	42 51	43 19	40 58	—

* Only approximate.

Specimens 1, 2, 5, 6, and 8, see table I; 10, B.M.1911,145, Jakuben, Tetschen, Bohemia; 11, B.M.1929,339, Zirkowitz, Bohemia; 12, B.M.1918,133, Salesl; 13, B.M.48663, Salesl.

The measurements were carried out as follows: the goniometer was adjusted with the axes of the first and third circles coincident and the axis of the second circle coincident with the reference line; the crystal was then mounted and the zone *mm'* brought into adjustment; this zone was measured with the third circle, and the bisector of the angle (110):(1$\bar{1}$0) (the normal to the face *a*, which is not developed except on the South African and Jakuben crystals, for which it was accordingly adjusted direct) brought into coincidence with the reference line; then by rotating the first and second circles through 90°, the absent face *c* (001) is brought into face adjustment, and readings on the first circle give values of *cp* (*p* being any face), while the third circle gives the interzonal angles $[ca]:[cp]$.

Following G. Kalb (1930), v_1, v_2, and v_3 are used for the three vicinal planes replacing *o* (111); the largest and nearest to the true *o* (111) is v_1.

The calculated value of *am* and $[ca]:[co]$ is 44° 26½′, and of *co* 26° 47½′, from the adopted axial ratio.

Both the new measurements and the data from the literature show that the face *m* (110) is fairly often present in its true position, and

[1] Min. Mag., 1932, vol. 23, p. 66.

that when replaced by a vicinal face, the replacing face is on the a (100) side of the true position of m (110). The presence of the true m-face and a vicinal face together has not been observed. As Kalb observed, o (111) is commonly replaced by a three-faced vicinal pyramid, the faces of which are often approximately in the zones $[10\bar{1}]$, $[0\bar{1}1]$, and $[110]$, and one face of which (that nearest the true

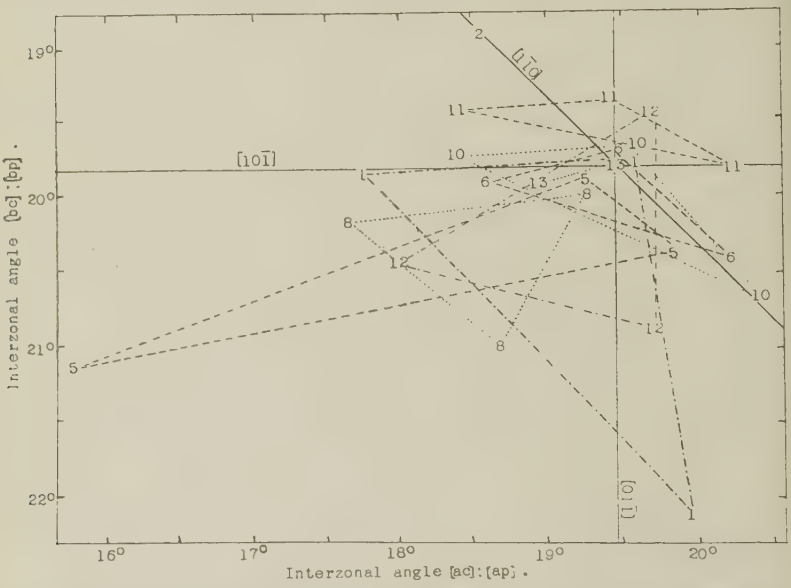

Fig. 2. A portion of a gnomonic projection (projection radius 100 cm.), showing the distribution of the faces vicinal to (111) on a number of natrolite crystals from different localities.

position of o (111), which is commonly approximately in the zone $[0\bar{1}1]$) is always much larger than the other two. Sometimes one, and very occasionally both, of the smaller vicinal faces may be suppressed. The large face has commonly been assumed to be the true o (111), and the smaller faces have often been assigned indices such as (10.11.11), (40.40.39), &c.

The new measurements indicate that the two smaller vicinal faces are often decidedly out of the zones $[10\bar{1}]$ and $[1\bar{1}0]$, especially the latter, which in several specimens has been observed to lie nearer zone $[0\bar{1}1]$. Fig. 2, in which the new data on the vicinal faces replacing o (111) are shown graphically in the form of a small section of a gnomonic projection on c (001) (with a radius of projection of

100 cm.), shows how the largest face of the three lies fairly near the true position of o (111), while the other two lie, one between o and m, but generally nearer a than the zone $[1\bar{1}0]$, and the other between o (111) and o' $(1\bar{1}1)$, often fairly closely in the zone $[10\bar{1}]$, but sometimes decidedly out in the direction of a.

Much more interesting results were obtained with the crystals from the Benallt manganese mine near Rhiw, Carnarvonshire. These magnificent crystals, up to 3·5 cm. in length and 0·4 cm. square, were discovered in 1911 by Mr. Arthur Russell, and have not hitherto been described. There are also unterminated crystal fragments up to 5 cm. in length and 1 cm. square. When first found, the crystals were water-clear, but they tend to become white and almost opaque unless kept in a closed tube. The cause of this change has not been elucidated; the opaque crystals do not appear to have lost any considerable amount of water, nor do they recover their transparency when kept over water for six months.

The measurements made on these crystals are summarized in table III, together with some observations made by Dr. L. J. Spencer in May 1911 and not hitherto published, and a typical crystal is shown in fig. 3. The forms developed are: m (110), reflects well, but is plentifully sprinkled with natural etch-figures; o (111), reflects fairly well, also carries numerous etch-figures; a (100) and b (010), narrow and rather dull; z (331) and π (551), matt, reflect poorly, and tend to alternate, occurring as plane patches in the curved tracts between o and m shown in the figure; D (101) and e (011), very narrow but fairly bright. From the curved tract between m and o, diffuse reflections are also obtained in the positions corresponding to ω_1 (332), ω_2 (441), and ω_3 (991) or (10.10.1).

The natural etch-figures on o (111) (fig. 4) are small triangular pits, bounded by faces of z (331), D (101), and e (011). Those on m (110) are quadrilaterals, and are of particular interest, as their shape and relative orientation on adjacent m-faces indicate the symmetry-class of natrolite to be didigonal polar, C_{2v}, with the c-axis as polar axis;[1] they are pits, generally bounded by four faces, and wedge-shaped, but the larger ones may have a plane bottom parallel to the m-face they are on. The other bounding planes are: at the side of the pits nearest a (100), usually γ_1 (230), but a few pits show γ_2 (340), γ_3 (350), n (120), or γ_4 (250); at the side of the pits nearest b (010), usually a (100), δ_2 (11.2.0), or δ (310), but a few pits showed δ_3 (520), δ_4 (210),

[1] Cf., however, below, under pyroelectricity and X-ray work.

or δ_5 (10.7.0); at the lower end of the pits, nearest the attached end of the crystals, a face a truly in the zone mo [1$\bar{1}$0], and inclined at

TABLE III. Goniometric measurements on Benallt natrolite, by the author and Dr. L. J. Spencer.

Angle.	Meas. (M. H. H.).	Meas. (L. J. S.).	Calc.
ma (110)(100)	44° 45′, 44° 10′	44°, 44½°	44° 26½′
mm' (110)(1$\bar{1}$0)	87° 56′ to 89° 50′	88° 28′ to 89° 4′ Cleavage, 88° 55½′	88 53
mb (110)(010)	45° 3′, 45° 24′	45° 20′, 45° 35′, 45° 46′	45 33½
mo (110)(111)	62½° to 64°	63° 6′, 63° 7′, 63½°	63 12½
$m\omega_1$(110)(332)	52°, 52½°	—	52 51
mz (110)(331)	33° 20′, 33½°, 37°	33½°, 34°, 36¾°	33 25
$m\omega_2$(110)(441)	26°, 24½°, 27°	27¾°	26 20
$m\pi$ (110)(551)	18° to 21° 20′	21½°, 21° 34′	21 36
$m\omega_3$(110)(hh1)	12°	—	12 24 * 11 12 †
be (010)(011)	72°	70°, 71°	70 31
aD (100)(101)	70°, 72°	—	70 10
[ma][mo]	90°, 89½°, 90°, 89°	—	90 0
Angles of etch-figures on m (110):—			
$m\alpha$	9°, 10°, 6½°, 7½°, 6°, 8–13½°	11° 21′, 11° 5′, 14°	—
[mo][$m\alpha$]	0°, 0° 10′, 0° 20′, 0°, 0°	—	—
$m\beta$	3° 10′, 2° 30′, 3° 20′, 2° 50′, 4° 30′, 3° 20′, 3° 20′, 2°, 3°, 3°	4° 19′	—
[mo][$m\beta$]	3° 50′, 4° 30′, 4° 10′, 4° 10′, 2° 40′, 2° 50′, 2° 20′, 2° 20′, 2° 40′, 3°, 2½°	≠ 0°	—
$m\gamma_1$(110)(230)	10° 50′, 10° 34′, 10½–11½°, 10° 40′, 10° 45′, 10° 15′, 11°	—	11 21
$m\gamma_2$(110)(340)	8½°, 7° 30′, 7°	—	8 9
$m\gamma_3$(110)(350)	14° 12′	14°	14 6
mn (110)(120)	17° 30′, 17° 15′, 18°, 19°, 18°	—	18 32½
$m\gamma_4$(110)(250)	21–22°, 23–25°	—	23 22
$m\delta$ (110)(310)	27½°, 26°, 26°	—	26 20
ma (110)(100)	43° 42′, 43° 56′, 43° 42′, 45°	—	44 26½
$m\delta_2$(110)(11.2.0)	34° 3′, 34° 20′, 34°	32½°	34 20
$m\delta_3$(110)(520)	22½°	—	23 2
$m\delta_4$(110)(210)	17° 37′	—	18 19
$m\delta_5$(110)(10.7.0)	9° 34′, 9° 33′	—	9 54½

* (110)(991). † (110)(10.10.1).

various angles to m in different pits—6°, 10°, 11½°, and 14° inclinations were noted, while some pits appear to have this face curved, with a slope ranging from 8° to 14°, i.e. from (881) to (14.14.1); at the upper end of the pits, nearest the terminated end of the crystals, a curved vicinal tract β, the inclination of which to m (110) generally ranges from 2° 0′ to 4° 30′, and which is decidedly out of the zone mo [1$\bar{1}$0], the interzonal angle $[mo]:[m\beta]$ being about 2½–4½°. In fig. 4 are shown drawings of some of these etch-figures made with a camera lucida; their actual size is 1–1½ mm. in length.

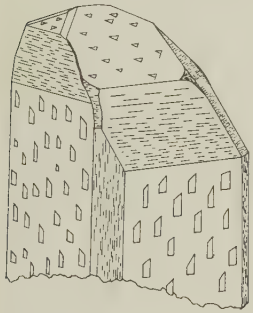

Fig. 3.

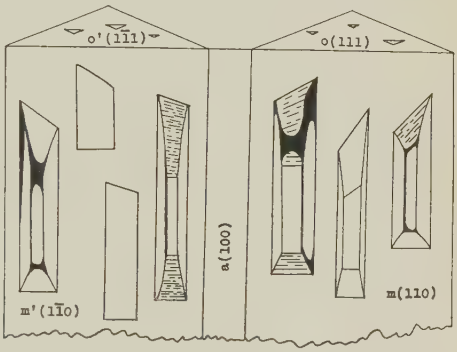

Fig. 4.

Fig. 3. Measured crystal of natrolite from Benallt, Carnarvonshire. Set up with a (100) in front.

Fig. 4. Natural etch-figures on one of the measured crystals of natrolite from Benallt, Carnarvonshire.

R. J. Haüy (1801) and J. D. Forbes (1834) found mesotype to be pyroelectric, but since mesotype included scolecite and mesolite as well as natrolite, this result is indefinite. P. Reiss and G. Rose (1843) studied crystals of natrolite from the Faeroe Isles, Fassa-thal, Langesundfjord, Puy-de-Dôme, and Jakuben, none of which they found to be pyroelectric. W. G. Hankel (1879), working with material from the Langesundfjord region, found certain pyroelectric effects, but they were not such as to enable any conclusions as to the symmetry-class to be made, and were probably false pyroelectricity, due to distortion of the crystal by uneven heating.

The available data being so unsatisfactory, it was evidently desirable to obtain new evidence of the pyroelectric behaviour of natrolite. Dr. W. H. Taylor kindly undertook to examine three plates of the Benallt material, cut perpendicular to the three

principal axes. The experiments, made by Mr. C. A. Meek in the Department of Physics of the University of Manchester, using the liquid air method,[1] showed conclusively that natrolite is weakly pyroelectric, with a single polar axis, the *c*-axis. This is in agreement with the results of the study of the natural etch-figures, showing that the *c*-axis is polar, and the symmetry class didigonal polar (orthorhombic hemimorphic), C_{2v}. Other work, however, suggests that natrolite is probably really monoclinic, though very closely pseudo-orthorhombic (see p. 283 below). The etch-figures and pyroelectric data would then fix the symmetry-class as digonal polar (monoclinic hemimorphic or sphenoidal), C_2.

Since this work was completed, F. Halla and E. Mehl (1932) have found that natrolite is piezoelectric; they do not, however, state which is the piezoelectric axis.

Parallel growths of natrolite with thomsonite have been observed by J. E. Hibsch (1917) on specimens from Jakuben, and from the Morwaner Bach, Salesl (both in Bohemia). Parallel growths with scolecite, from Bishopton, Renfrewshire, are described by G. Cesàro (1909). Needles of mesolite tipped with natrolite, from Kara-dagh, Crimea, are described by Miss O. A. Brinken (1914), while natrolite needles tipped with mesolite, from Fuchsberg, Salesl, are described by J. E. Hibsch (1917). The last type of association has been observed by the author on several specimens from the Neubauerberg, Mickenhan, Böhmisch-Leipa; the long (up to 2 cm.), hair-fine needles of natrolite are terminated by the pyramid *o* (111), as usual, and an extension of mesolite in parallel position continues the needles, sometimes as much as 1 cm. farther in length; on other specimens, the mesolite forms a very thin coating over the whole of the natrolite needle (prism faces as well as pyramid). These parallel growths present a striking appearance under the polarizing microscope, the natrolite polarizing in brilliant colours, while the mesolite is apparently isotropic. I have since found that A. Scheit (1911) has also described this occurrence.

It may perhaps be noted here that whereas F. Zambonini (1908) doubts the occurrence of natrolite on Monte Somma, Vesuvius, there is a specimen in the British Museum (B.M. 95048), from the Vesuvian collection of T. Monticelli, which optical and chemical tests show to be definitely natrolite.

There are a fair number of determinations of the specific gravity

[1] A. J. P. Martin, Min. Mag., 1931, vol. 22, p. 519.

of natrolite in the literature. The most reliable, twelve in number, range from 2·234 to 2·257, with a mean of 2·249. Less accurate determinations, and determinations made on impure or unsuitable material, 24 in number, range from 1·953 for a fine-grained lehuntite to 2·39 for an impure spreustein. The specific gravity of each of the analysed specimens (table I) has been determined, the results ranging from 2·238 to 2·250. The specific gravity must, however, be affected by the potassium content (the calcium content will have little effect, since two sodium atoms have nearly the same weight as one calcium atom); after allowing for the change of cell-size due to the replacement of sodium by potassium (see p. 278), there must be an increase in the specific gravity amounting to 0·0088 per potassium atom per unit cell replacing sodium; artificial base exchange produces just such an increase (see table VIII). After making this correction for all the specific gravity determinations for which the necessary chemical data are available (the eight of table I, and five from the literature[1]) we arrive at a mean figure of 2·242 for the probable specific gravity of fully hydrated potash-free natrolite.

Since the space-group determinations by A. L. Parsons (1930), L. Pauling (1930), F. Halla and E. Mehl (1930 and 1932), and J. Wyart (1931) do not agree, Mr. F. A. Bannister has undertaken a re-examination of the matter. Parsons's space-group results are definitely incorrect. Pauling and Wyart both assign the space-group C_{2v}^{19}, while Halla and Mehl concluded at first (1930) that it is C_{2v}^{18}, D_2^7, or D_{2h}^{23}, since they observed the diffractions (024), (028), (402), (802), and (204), which should be absent for C_{2v}^{19}; but in their second paper (1932) they suggest that these observed diffractions are due to local lattice distortion ('Gitterstörungen'), or perhaps to small crystals attached to the principal one. Mr. Bannister has carefully examined several crystals, from Salesl and Kimberley; the diffractions (402), (042), (802), and (082) were observed repeatedly on rotation and oscillation photographs, but were always extremely weak. The first pair are stronger than the second, but their intensity is no more than perhaps 1/100 of that of an ordinary 'very weak' line. Diffractions (20.0.2), (10.0.4), and (14.0.4) could not be detected (Halla and Mehl found (802) stronger than (402)). Since the 'anomalous' diffractions appear with the same intensity on photographs of several crystals from two different localities, Halla and Mehl's explanations

[1] See G. J. Brush, 1861; A. Pelikan, 1902; B. J. Harrington, 1906; G. Tschermak, 1917; and T. L. Walker and A. L. Parsons, 1922.

(1932) seem untenable; the diffractions must be 'real', and the space-group cannot be strictly C_{2v}^{19}, though it approximates very closely to it.

The diffractions are all to be expected if the space-group is C_{2v}^{18}; but W. H. Taylor[1] has found it impossible to build up a satisfactory structure for natrolite in this space-group, whereas in C_{2v}^{19} a good structure could be found. The most reasonable explanation seems to be that natrolite is not truly orthorhombic. It is monoclinic, elongated along the symmetry-axis, with β 90° 0′ and space-group C_2^3, but with an extremely close approximation to the orthorhombic symmetry C_{2v}^{19}, of which C_2^3 is a sub-group. This conclusion agrees with the X-ray data, but no optical evidence could be found to support it. On the other hand, it explains the continuity which vapour-pressure and X-ray work seem to indicate between natrolite and anhydrous metanatrolite, which is definitely monoclinic (see further under metanatrolite, below).

While this seems the most probable explanation of the anomalous diffractions, further work on the subject is desirable. It would be of particular interest to investigate whether they persist at liquid-air temperatures, and whether they are shown by the base-exchange products derived from natrolite, and by the most lime-free natrolites.

The unit-cell dimensions of natrolite are a 18·31 ± 0·04, b 18·66 ± 0·04, and c 6·60 ± 0·02 Å., according to Mr. Bannister's measurements on crystals from Salesl (no. 2, table I) and Kimberley (no. 6, table I). From these values, together with the analytical figures and specific gravities, the number of oxygen atoms per unit cell was calculated for each specimen analysed, the results being included in table I. It will be observed that they all tend to be rather higher than 80, but the source of error could not be traced. The cell dimensions found by Parsons, Pauling, Halla and Mehl, and Wyart are all in fairly good agreement with the present figures.[2]

Optics.

The first investigation of the optical properties of natrolite appears to have been by Sir David Brewster (1821, 1822), who examined material from Puy-de-Dôme and from Hohentwiel. He distinguished

[1] Private communication.

[2] Halla and Mehl's value for the unit cell content, 7·8 molecules of $Na_2Al_2Si_3O_{10}.2H_2O$, is inaccurate owing to their use of an incorrect molecular weight; the true figure, from their cell-dimensions and specific gravity, is 8·17 molecules.

between natrolite and the other mesotypes and thomsonite, and also, for some reason, between natrolite from the two occurrences mentioned, but unfortunately never seems to have published the promised account of his results. The earliest available data are therefore those of A. Des Cloizeaux (1857, 1858, 1862), who showed that the optic axial plane is parallel to b (010) and the positive acute bisectrix perpendicular to c (001), the optic axial angle, 2E, being 90–100°, with $\rho < v$.

Des Cloizeaux found straight extinction, and optics in all ways consistent with orthorhombic symmetry, but O. Luedecke (1881) found extinction-angles of 5–6° on m (110) on crystals from Aussig and Salesl; oblique extinction has also been observed by A. von Lasaulx (1881) on crystals from Trezza, Aci Castello, Sicily, $3\frac{1}{2}$–$4\frac{1}{2}$°; by W. C. Brøgger (1889) on Norwegian crystals, $1\frac{1}{2}$–3°; and by S. J. Thugutt (1911) on 'epinatrolite' from Sauerbrunnenstrasse, Karlsbad, 5–6°. On the other hand, O. Schmidt (1886) could find no evidence of monoclinic symmetry on crystals from Brevig, Aussig, or Salesl, nor could E. Artini (1887) on crystals from several localities, nor J. E. Hibsch (1917) on a large number of crystals from Salesl. The author has examined hundreds of crystals, from most of the localities represented in the British Museum collection, and has never met with any which failed to give perfectly straight extinction on m; one or two sub-parallel groups gave anomalous effects, but on crushing these, the cleavage fragments all extinguished straight. Many of these crystals were potassiferous (Brøgger suggested that monoclinic natrolites were essentially potassiferous, the extinction-angle increasing with the potassium content). It cannot therefore be said that there is at present any satisfactory evidence for the existence of monoclinic natrolites with the symmetry-axis perpendicular to the elongation. But the causes of the observed extinction-angles are not yet clear; imperfect adjustment of apparatus, vicinal faces, and sub-parallel growths have all been suggested.

After the X-ray work had shown that the space-group of natrolite cannot be truly C_{2v}^{19}, and is probably C_2^3, the symmetry-axis being parallel to the elongation, several cut plates of the Benallt material were re-examined. No trace of monoclinic dispersion of the bisectrices could be found, nor any departure of the extinction on c from diagonal. The departure of the symmetry from orthorhombic must therefore be extremely small.

Several sets of measurements of the refractive indices of natrolite

have been published,[1] but with the exception of one by S. Di Franco (1929), all have been made on unanalysed material; it is not clear from Di Franco's analysis whether lime and potash were really absent, or merely left undetermined. There are several sets of optic axial angle determinations in the literature,[2] but only those by W. C. Brøgger (1889) and E. Artini (1887) were made on analysed material (Artini's material was analysed by G. B. Negri (1890)).

The author has made refractive index determinations by the prism method on four, and optic axial angle determinations on six analysed specimens. The optic axial angle determinations were made with crystal fragments immersed in a liquid of refractive index equal to the refractive index β of the crystal, giving 2V direct, except for the Benallt material; a large plate of the latter, cut perpendicular to the c-axis, gave 2E. The figures for the Benallt material are decidedly the most accurate, since the prisms cut from these large crystals have polished refracting surfaces about 3 mm. square.

The large plate of the Benallt natrolite cut perpendicular to the c-axis also served for direct measurements of $\beta - \alpha$. These were made at the same time as the optic axial angle measurements, the wave-length of the light being adjusted by the monochromator so that the centre of the interference-figure (i.e. the Bx) was dark, and the order of the interference involved found by counting the rings between the bisectrix and an optic axis. Between λ 4480 and 7320 Å., interferences in the 20th to the 35th order were obtained. The thickness of the plate (measured with a micrometer screw-gauge) is the chief source of error in these determinations, so that the relative values of $\beta - \alpha$ found for various wave-lengths are considerably more accurate than the absolute values.

Unfortunately, those specimens richest in lime and in potash were not suitable for refractive index determinations by the prism method; determinations by the immersion method showed no differences outside the limits of error ($\pm 0{\cdot}003$) from the indices found for the Benallt material. The differences between the refractive indices of the Benallt natrolite and of the other specimens measured by the prism method are barely outside the limits of experimental error, and could not be accurately correlated with the small variations in

[1] A. Des Cloizeaux, 1862; W. C. Brøgger, 1879; J. Lorenzen, 1889; K. Zimányi, 1894; S. Di Franco, 1929.

[2] A. Des Cloizeaux, 1862; W. C. Brøgger, 1879, 1889; E. Palla, 1884; E. Artini, 1887, 1888; J. Lorenzen, 1889; S. Di Franco, 1929.

TABLE IV *a*. Optical measurements on Benallt and Puy de Marmant natrolites (refractive indices and optic axial angles).

	Benallt, no. 4.					Puy de Marmant, no. 1.		
λ.	α.	β.	γ.	2E.	2V.	α.	γ.	2V.
7682	1·4737	1·4772	1·4856	100° 40′	62° 49′	—	—	—
7200	1·4747	1·4781	1·4866	100 20	62 36	1·4769	1·4890	—
7000	1·4756	1·4786	1·4876	100 38	62 44	1·4773	1·4894	—
6708	1·4764	1·4795	1·4887	100 51	62 48	1·4777	1·4898	59° 14′
6563	1·4768	1·4798	1·4892	100 56	62 50	1·4779	1·4900	—
6250	1·4777	1·4809	1·4899	101 2	62 50	1·4783	1·4901	59 34
6000	1·4787	1·4819	1·4909	101 24	62 58	1·4789	1·4912	—
5893	1·4789	1·4822	1·4911	101 36	63 3	1·4799	1·4918	59 37
5780	1·4796	1·4830	1·4918	101 43	63 4	1·4804	1·4925	59 40
5461	1·4805	1·4838	1·4923	101 53	63 7	1·4813	1·4938	59 44
5350	1·4811	1·4846	1·4931	102 6	63 11	1·4821	1·4946	59 41
5000	1·4829	1·4864	1·4957	102 8	63 11½	1·4842	1·4973	59 30
4916	1·4835	1·4868	—	—	—	—	—	—
4861	1·4837	1·4871	1·4965	101 56	63 4	1·4856	1·4988	59 14
4550	1·4860	1·4896	1·4993	101 42	62 45	1·4878	1·5017	59 8
4358	1·4878	1·4912	1·5011	101 26	62 32	1·4894	1·5035	—
4200	1·4897	1·4933	1·5027	101 18	62 22	—	—	—
4047	1·4924	1·4946	1·5048	—	—	—	—	—

Probable errors (excluding wave-lengths λ7682, 7200, 4200, and 4047): in the refractive indices, Benallt material, maximum ±0·0003, mean ±0·0001; Puy de Marmant material, ±0·0010; in the optic axial angles, Benallt material, maximum ±4′, mean ±1½′; Puy de Marmant material, ±10′.

TABLE IV *b*. Optical measurements on Cape Blomidon, Salesl, Kimberley, and Snake Hill natrolites (refractive indices and optic axial angles).

	Cape Blomidon, no. 5.			Salesl, no. 2.		Kimberley, no. 6.	Snake Hill, no. 8.
λ.	α.	γ.	2V.	α.	γ.	2V.	2V.
7000	—	1·4853	—	—	—	—	—
6708	1·4750	1·4865	61° 31′	1·4780	1·4891	63° 20′	—
6563	1·4764	1·4881	—	—	1·4898	—	—
6250	1·4780	1·4887	61 40	—	1·4905	63 51	—
6000	1·4792	1·4895	—	—	1·4912	—	—
5893	1·4800	1·4901	61 44	1·4806	1·4919	64 0	60°±1°
5780	1·4806	1·4907	61 45	—	1·4921	64 10	—
5461	1·4812	1·4916	61 45	—	1·4926	64 20	—
5350	1·4818	1·4922	61 48	1·4825	1·4935	64 25	—
5000	1·4836	1·4937	61 40	—	1·4948	64 23	—
4861	1·4842	1·4943	61 25	—	1·4957	64 7	—
4550	—	1·4960	—	—	—	—	—

Maximum probable error in the refractive indices, ±0·0010.

TABLE IV *c*. Optical measurements on Benallt natrolite, no. 4 (birefrigence). Interferences with a plate 4·55 mm. thick ⊥ *c* (001), in several orders.

λ.	β − α.	Order.	λ.	β − α.	Order.
7320	0·003210	20th	5420	0·003328	28th
6960	3225	21	5250	3337	29
6708	3236	22	5110	3362	30
6470	3265	23	4970	3379	31
6220	3274	24	4830	3390	32
5990	3284	25	4700	3402	33
5780	3296	26	4590	3423	34
5610	0·003322	27th	4480	0·003439	35th

chemical composition; there is some evidence that increase in lime lowers the refractive index slightly, while potash has little effect (see further under base-exchange, below). No variations in the birefringence, $\gamma - \alpha$, or dispersion with the small amounts of lime and potash were detected. The optic axial angle shows fairly considerable variations, which appear to arise from variations in $\beta - \alpha$, but these again could not be correlated with the changes in chemical composition.

All these optical data are collected in tables IV *a*, *b*, and *c*. The refractive index and birefringence curves (fig. 5 shows those of the Benallt material only, the others falling too close to be distinguished) present nothing of particular note, but the measurements of 2E and 2V (fig. 6) for a large number of wave-lengths disclosed one point of some interest. The dispersion of the optic axial angle is usually given as $\rho < v$, and the angle does indeed increase steadily from the red to the blue-green, but on taking the measurements farther, it was found that 2E shows a maximum at λ 5150 Å., decreasing again for blue and violet light. No measurements had previously been made in this portion of the spectrum. The internal angle, 2V, shows a similar behaviour (both in the Benallt material and in the other measured specimens); from the red to λ 5150 in the blue-green it increases steadily, then falls sharply, and for the violet is less than for the red.

The exact orientation of the prisms used for refractive index measurements was in every case measured on the goniometer, and a correction for imperfect orientation applied to the refractive indices found by the usual formulae. The accuracy of the work on the Benallt material was checked by comparing the two values of α found with the two prisms; a further check was obtained by comparing the

values of $\beta - \alpha$ and $\gamma - \alpha$ obtained as differences in the refractive index measurements with the directly determined values of $\beta - \alpha$ and the values of $\gamma - \alpha$ computed from $\beta - \alpha$, 2E, and β. Except for the

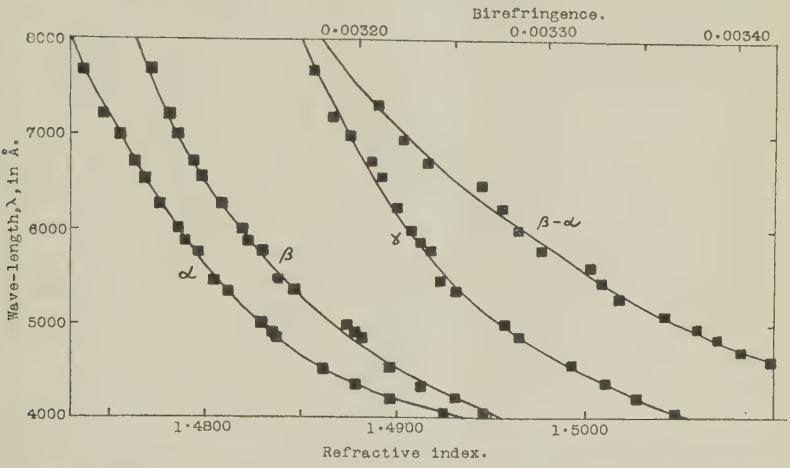

FIG. 5. The variation of the refractive indices and birefringence ($\beta - \alpha$) of natrolite from Benallt, Carnarvonshire, with the wave-length of the light.

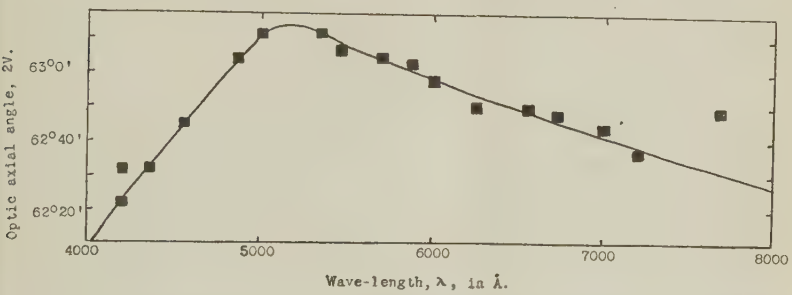

FIG. 6. The variation of the optic axial angle, 2V, of natrolite from Benallt, Carnarvonshire, with the wave-length of the light.

far red and far violet, the agreement was very good. The maximum and average probable errors so found are noted in table IV*a*. The probable errors for the other specimens are estimated.

The mean dielectric constant of natrolite (a quantity closely related to the refractive index) has been measured by E. E. Fairbanks (1926), who found $\epsilon = 11 \pm 1$ at 31° C.; measurements of the dielectric constant along the three crystallographic axes would be of considerable interest, but have never been attempted.

Dehydration and vapour-pressure.

Several studies have been made of the dehydration of natrolite. F. Rinne (1890) was interested only in the complete dehydration, which leads to metanatrolite (see below). G. Tammann (1897) made a set of isothermal observations at the ordinary temperature; his curve runs parallel to the isothermal dehydration curve for 20° C. deduced from the author's vapour-pressure observations, but there are two discrepancies. In the first place, the losses of water when the saturated zeolite was exposed over sulphuric acid of various concentrations are throughout higher than would be expected from the author's results by about 0·25%; this is the amount Tammann found to be lost at a water vapour-pressure of 12·5 mm. Hg. The author's curves show that the vapour-pressure of fully hydrated natrolite is considerably less than that of water, being about 8 mm. at 20° C. (that of water is 17·4 mm. at 20° C.), and it appears probable that the excess 0·25% water absorbed when natrolite is exposed to saturated water-vapour is merely adsorbed, not included in the lattice; this would account for the steep fall of this first part of Tammann's curve, followed by a more gradual slope as the true crystal water is removed.

The second discrepancy is that if this first 0·25% water is accepted as merely adsorbed, Tammann's water determination shows the fully hydrated natrolite as still containing 10·15% water, considerably in excess of 16 mols. per unit cell. But Tammann determined the water as loss on ignition, and it is readily shown that, on ignition, natrolite loses a part of its soda as well as the water, thus explaining Tammann's high result.

The isobaric dehydration of natrolite has been studied by F. Zambonini (1906, 1908) and by A. Cavinato (1927), with very different results. Observations by the rough method of dehydration in an oven without any attempt at control of the water vapour-pressure have been made by several workers,[1] with very variable results. The author has carried out a few isobaric dehydrations of natrolite which have only served to convince him that the approach to equilibrium is extremely slow, and that even so long as 8 hours is often insufficient for its attainment. The various studies, however,

[1] A. Damour, 1858; C. Hersch, 1887; W. H. Melville, 1892; G. Friedel, 1899; F. W. Clarke and G. Steiger, 1900; G. Stoklossa, 1918; A. Beutell, 1921; T. L. Walker and A. L. Parsons, 1922; S. Di Franco, 1929.

serve to show the general character of the isobaric curve; dehydration is at first very slow and gradual, until a temperature variously given as from 240 to 300° C. (for a water vapour-pressure of 10 mm.) is reached, when a rapid loss of water takes place, and the crystals, previously clear, become opaque, fragile, and porcellaneous. At about 350° C. dehydration is complete.

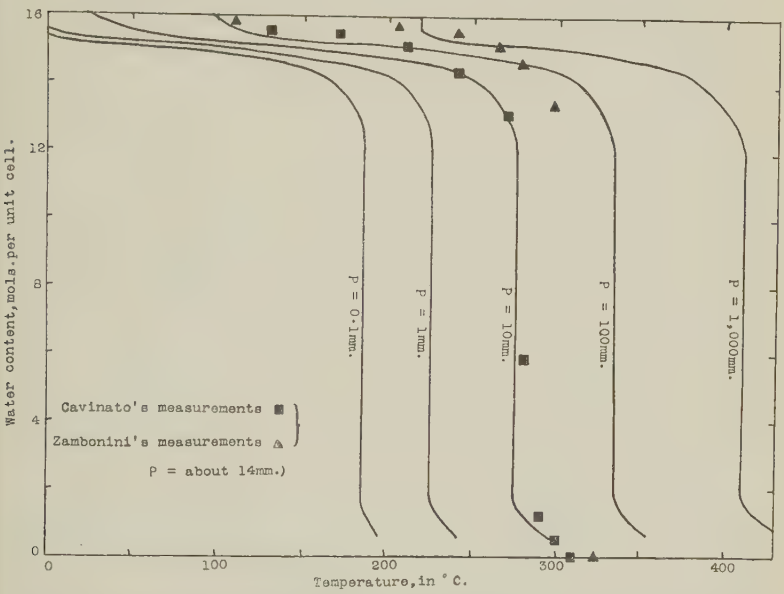

FIG. 7. Isobaric dehydration curves of natrolite (specimen no. 2, from Salesl, Bohemia), together with the isobaric dehydration results of Zambonini (1906, 1908) and Cavinato (1927).

The vapour-pressure experiments leave no doubt as to the true course of the isobaric curves, and the computed isobaric curve for a water vapour-pressure of 10 mm. Hg agrees quite well with Cavinato's results for temperatures above 240° C., but only badly below. The computed isobaric curves, from the vapour-pressure data, are shown in fig. 7, together with the experimental results of Zambonini and Cavinato for a vapour-pressure of about 14 mm.

The vapour-pressure measurements were made with the apparatus and in the manner previously described and figured,[1] and are tabulated and graphed in the same way. One or two slight modifications

[1] Part II of this series, loc. cit.

were, however, made in the apparatus, which experience had proved desirable. The narrow tube connecting the zeolite bulb, *Z*, with the null manometer was lengthened, to ensure avoidance of the trouble met with in the work on thomsonite, of uneven heating of the zeolite due to its shifting in the bulb and getting too near the outside of the oven.

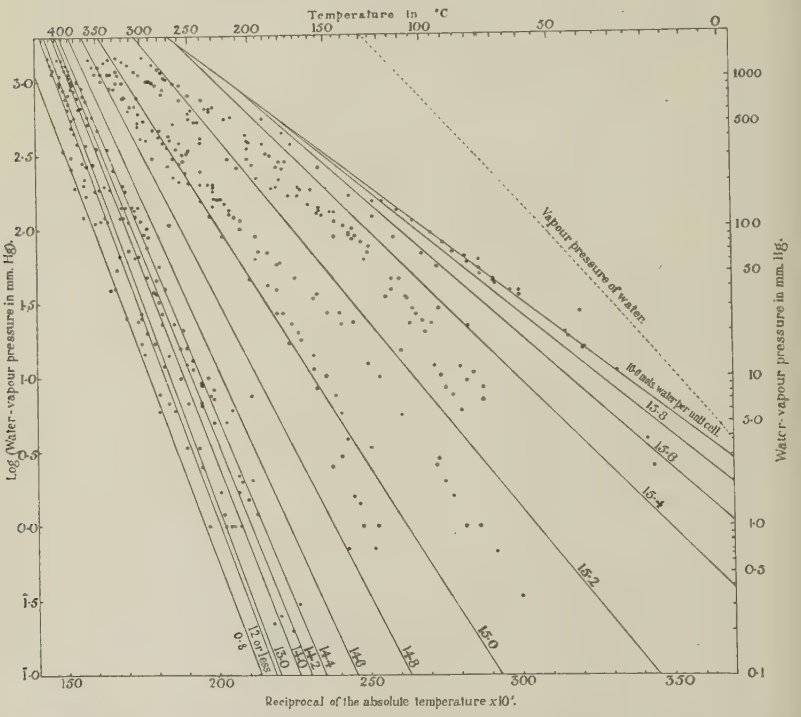

FIG. 8. Isohydric vapour-pressure curves of natrolite (specimen no. 2, from Salesl, Bohemia).

The tube between the bulb *B* and the tap *H* was lengthened and bent over at right angles, so as to avoid the heat rising from the auxiliary oven *O*, which tended to soften the tap-grease and make the tap leak in its former position. Lastly, a new main manometer was installed, with a range up to 1450 mm. Hg pressure, while a good high-temperature thermometer enabled the temperature range to be extended to about 420° C.

The results obtained (table V) were satisfactory, equilibrium being rapidly established with either rising or falling temperature, and

repeat observations were in good agreement. The greatest error is in measurement of the temperature, which may occasionally be out by as much as 5° C. A thermocouple would be more suitable for this measurement, but was not available.

Fig. 8 shows the isohydric curves plotted from the experimental data. The molecular heats of hydration, Q, for different degrees

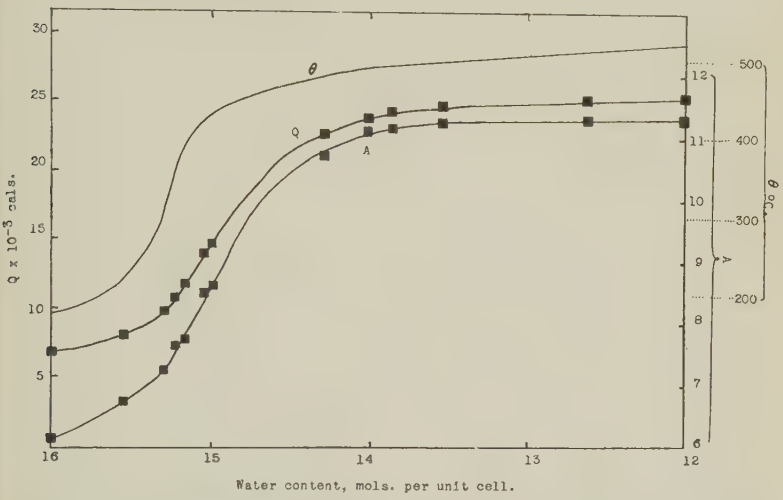

Fig. 9. The variation, with the water content, of the molecular heat of hydration (Q) of natrolite, the integration constant (A) of the equation

$$\log_{10} p = A - Q/RT(\log_e 10),$$

and the temperature (θ) at which the isohydric curve for fully hydrated natrolite cuts the isohydric curve for natrolite of a lower degree of hydration.

of hydration, and the integration constants, A, of the equation $\log_{10} p = A - Q/RT\ (\log_e 10)$ (where T is the absolute temperature and p the water vapour-pressure in mm. Hg) are listed in table VI and plotted in fig. 9. As with thomsonite, the procedure adopted was to deduce Q and A from the low-pressure region of the experimental curves, then to plot Q and A against the degree of hydration, and to draw 'theoretical' isohydric lines, assumed straight, by means of Q and A values interpolated from this plot. Isothermal curves were also computed, but are not reproduced, as they give no additional information. Computed isobaric curves are shown in fig. 7. In the high-pressure region of the experimental data, where the dead-space loss of water causes an appreciable departure of the experimental

curves from the true isohydric lines,[1] the agreement between observed and calculated pressures is still quite good (see table V).

TABLE V. The vapour-pressure of natrolite (Salesl, B.M. 49545) at various degrees of hydration. (Results plotted in fig. 8.)

c = water content, mols. per unit cell; t = temperature, in °C.; p = water vapour-pressure in mm. Hg; $p_{calc.}$ = water vapour-pressure calculated from the isohydric curves of fig. 8; + temperature rising; − temperature falling; ? doubtful equilibrium.

Series 1.					
c.	p.	t.	Log p.	Log $p_{calc.}$	Notes.
16·00	3·8	19	0·58	0·87	?*
15·99	32	60	1·55	1·51	+
16·00	20	45	1·30	1·29	−
16·00	11	28	1·04	1·03	−
15·99	38	64	1·58	1·56	+
16·00	18·5	44	1·27	1·37	−
16·00	16	39	1·20	1·20	−
15·99	48·5	75	1·69	1·71	+
15·99	42	69	1·62	1·62	−
15·99	46	70	1·66	1·63	+
15·99	40	70	1·60	1·63	+
15·98	54	76	1·73	1·71	−
15·98	58·5	80	1·77	1·77	+
15·98	65	81	1·81	1·78	+
15·98	69	86	1·84	1·85	+
15·97	80	90	1·90	1·90	+
15·97	94	96	1·97	1·97	+
15·97	112	105	2·05	2·06	+
15·96	132	112	2·12	2·13	+
15·95	151	119	2·18	2·21	+
Series 2.†					
15·55	55	93	1·74	1·72	+
15·55	68	100	1·83	1·81	+
15·55	87	113	1·94	1·98	+
15·54	121	124	2·08	2·10	+
15·53	167	137	2·22	2·24	+
15·52	259	154	2·41	2·42	+
15·50	371	171	2·57	2·56	+
15·50	432	178	2·64	2·62	+
15·48	556	191	2·74	2·84	+

Series 3.†					
c.	p.	t.	Log p.	Log $p_{calc.}$	Notes.
15·17	0·34	60	$\bar{1}$·53	$\bar{1}$·75	+
15·17	0·17	45	$\bar{1}$·23	$\bar{1}$·35	−
15·17	0·68	70	$\bar{1}$·83	$\bar{1}$·96	+
15·17	1·0	76	0·00	0·11	+
15·17	1·0	81	0·00	0·23	+
15·17	1·6	86	0·20	0·33	+
15·17	2·0	90	0·30	0·42	+
15·17	2·6	94	0·41	0·50	+
15·17	4·4	103	0·64	0·66	+
15·17	10·0	120	1·00	0·98	+
15·17	5·6	110	0·74	0·79	−
15·17	12·4	127	1·09	1·09	−
15·16	23	143	1·43	1·32	+
15·14	58	182	1·76	1·84	+
15·15	34	158	1·53	1·52	+
15·16	23	142	1·36	1·31	+
15·16	27	149	1·43	1·44	+
15·16	36	157	1·56	1·53	+
15·15	47	170	1·67	1·69	+
15·15	59	180	1·77	1·82	+
15·14	69	188	1·84	1·92	+
15·13	89	195	1·95	2·01	+
15·12	161	229	2·21	2·37	+?
15·13	148	220	2·17	2·31	−
15·13	131	216	2·12	2·26	−
15·13	111	208	2·05	2·17	−
15·12	159	225	2·20	2·33	+
15·13	135	216	2·13	2·26	−
15·11	201	240	2·30	2·50	+
15·09	277	258	2·44	2·69	+
15·07	344	270	2·55	2·73	+

* After standing 10 days at room-temperature.

† Owing to an accident to the apparatus, the water contents of these series are only approximate.

[1] With thomsonite, the maximal pressures measurable by the apparatus being so much lower, the dead-space loss was not noticeable.

TABLE V (*continued*).

Series 3 (*continued*).†

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
15·07	380	275	2·58	2·76	+
15·06	415	280	2·62	2·78	+
15·05	470	286	2·67	2·84	+
15·03	540	295	2·73	2·91	+
15·02	600	300	2·78	2·93	+
15·00	680	310	2·83	2·99	+
15·00	680	305	2·83	2·96	−
14·93	980	325	2·99	3·03	+
14·91	1130	334	3·05	3·08	+
14·86	1358	340	3·13	3·10	+

Series 4.

15·30	9·5	81	0·98	1·07	+
15·30	30	100	1·48	1·38	+
15·29	41	114	1·69	1·58	+
15·29	79	126	1·88	1·74	+
15·28	99	135	2·00	1·84	+
15·28	128	146	2·11	1·98	+
15·30	20	98	1·30	1·35	+
15·30	26	103	1·42	1·42	+
15·30	29	105	1·46	1·45	+
15·29	43	114	1·63	1·59	+
15·29	57	122	1·76	1·70	+
15·29	85	135	1·93	1·88	+
15·29	111	145	2·05	2·01	+
15·28	139	155	2·14	2·09	+
15·27	190	168	2·28	2·21	+
15·26	256	181	2·41	2·36	+
15·30	6·0	83	0·78	1·10	+?
15·29	35	108	1·54	1·49	+
15·30	5.4	74	0·73	0·94	+?
15·30	6·8	78	0·83	1·01	+
15·30	7·4	83	0·87	1·10	+
15·30	23	96	1·36	1·32	+
15·30	46	114	1·66	1·60	+
15·29	89	134	1·95	1·85	+
15·28	128	148	2·11	2·01	+
15·27	182	159	2·26	2·11	+
15·26	250	178	2·40	2·31	+
15·26	298	203	2·47	2·60	+
15·26	270	198	2·43	2·48	+
15·25	406	220	2·61	2·54	+
15·22	522	239	2·72	2·84	+

Series 4 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
15·22	530	242	2·72	2·85	+
15·21	555	246	2·74	2·86	+
15·20	610	250	2·78	2·87	+
15·20	743	268	2·87	2·91	+
15·20	823	276	2·91	3·04	+
15·19	927	285	2·97	3·07	+
15·19	1000	290	3·00	3·10	+
15·19	1000	294	3·00	3·12	+
15·18	1100	300	3·04	3·14	+
15·15	1281	311	3·11	3·18	+
15·15	1350	318	3·13	3·22	+
15·14	1440	325	3·16	3·26	+
15·17	1180	306	3·07	3·15	−
15·19	989	287	2·99	3·09	−
15·19	873	275	2·94	3·03	−
15·20	630	249	2·80	2·86	−
15·25	350	202	2·54	2·58	+

Series 5.†

15·27	82	131	1·91	1·73	+
15·23	97	136	1·96	1·82	+
15·25	126	155	2·10	2·06	+
15·29	29	93	1·46	1·26	+
15·27	71	127	1·84	1·55	+
15·27	93	136	1·97	1·82	+
15·29	22	80	1·34	1·04	+
15·26	105	141	2·02	1·86	+
15·26	112	145	2·05	1·93	+
15·26	133	154	2·12	2·04	+
15·25	145	161	2·16	2·12	+
15·25	167	174	2·22	2·27	+
15·25	185	185	2·27	2·39	+
15·25	165	168	2·22	2·20	+
15·24	191	182	2·28	2·34	+
15·24	219	195	2·34	2·49	+
15·23	255	210	2·41	2·62	+
15·22	298	218	2·47	2·66	+
15·21	338	230	2·53	2·71	+
15·20	380	240	2·58	2·75	+
15·19	520	265	2·71	2·84	+

Series 6.

15·29	15·3	110	1·18	1·52	?
15·29	12·0	95	1·08	1·28	?

† Owing to an accident to the apparatus, the water contents of these series are only approximate.

TABLE V (*continued*).

Series 6 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
15·29	10·4	92	1·01	1·23	+
15·29	8·5	90	0·93	1·20	–
15·29	7·5	87	0·88	1·15	+
15·29	23	106	1·36	1·46	+
15·29	35	117	1·54	1·63	+
15·28	62	129	1·79	1·75	+
15·28	88	145	1·95	1·98	+
15·27	123	152	2·09	2·03	+
15·26	180	166	2·26	2·00	+
15·26	190	167	2·28	2·20	+
15·25	282	179	2·45	2·34	+
15·24	320	189	2·51	2·41	+
15·24	280	175	2·45	2·27	+
15·24	310	186	2·49	2·39	+
15·23	375	191	2·57	2·42	+
15·22	430	203	2·63	2·51	+
15·21	566	215	2·75	2·57	+
15·20	650	231	2·81	2·65	+
15·19	743	237	2·87	2·66	+
15·20	667	230	2·82	2·64	–
15·21	550	220	2·74	2·62	–
15·23	384	200	2·58	2·54	–
15·20	640	236	2·81	2·66	+
15·23	380	202	2·59	2·55	–
15·21	610	233	2·79	2·64	+
15·29	7·0	74	0·84	0·92	+
15·18	793	250	2·90	2·71	+
15·16	989	265	2·99	2·80	+
15·16	1013	272	3·01	2·87	+
15·14	1143	277	3·06	2·89	+
15·13	1280	286	3·11	2·98	+
15·11	1430	296	3·16	3·05	+
15·14	1210	280	3·08	2·92	–
15·16	1060	273	3·02	2·88	–
15·17	930	260	2·97	2·74	–
15·25	216	180	2·33	2·33	+

Series 7.

15·08	1·4	132	0·15	0·91	?
15·08	3·8	138	0·58	1·03	?
15·08	5·8	142	0·76	1·09	+
15·08	7·5	146	0·88	1·15	+
15·08	10·2	151	1·01	1·24	+
15·08	14	158	1·15	1·36	+
15·08	20	168	1·30	1·48	+

Series 7 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
15·08	39	182	1·59	1·72	+
15·07	63	196	1·80	1·90	+
15·07	100	207	2·00	2·05	+
15·06	126	216	2·10	2·12	+
15·06	157	223	2·20	2·18	+
15·05	190	230	2·28	2·24	+
15·08	18	166	1·25	1·48	+

Series 8.

15·05	0·7	139	$\bar{1}$·85	0·88	+?
15·05	2·5	147	0·40	1·04	?
15·05	8·5	156	0·93	1·19	+
15·05	11·5	158	1·06	1·22	+
15·05	23	172	1·36	1·44	+
15·05	27	178	1·43	1·53	+
15·04	46	188	1·62	1·64	+
15·04	70	195	1·85	1·73	+
15·03	122	213	2·08	1·95	+
15·02	200	229	2·30	2·15	+
15·01	246	239	2·39	2·24	+
15·00	336	250	2·53	2·35	+
15·00	382	258	2·58	2·44	+
15·00	326	252	2·51	2·36	+
15·03	140	230	2·15	2·16	+
15·02	206	250	2·31	2·39	+
15·01	236	254	2·38	2·41	+
15·01	314	262	2·50	2·44	+
14·99	426	269	2·63	2·54	+
15·00	400	268	2·60	2·54	–
15·01	350	262	2·54	2·50	–
15·01	286	251	2·46	2·44	–
15·01	296	260	2·47	2·53	+
14·99	470	278	2·67	2·64	+
14·95	770	303	2·89	2·83	+
14·94	980	318	2·99	2·97	+
14·92	1090	324	3·04	3·00	+
14·92	1181	325	3·07	3·02	+
14·89	1410	335	3·15	3·07	+

Series 9.

15·02	0·7	124	$\bar{1}$·85	0·44	?
15·02	1·0	122	0·00	0·41	?
15·02	3·4	126	0·53	0·47	+
15·02	1·0	130	0·00	0·57	?
15·02	1·6	136	0·20	0·68	+

TABLE V (*continued*).

Series 9 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
15·02	2·9	142	0·47	0·79	+
15·02	17	173	1·23	1·34	+
15·02	27	182	1·43	1·47	+
15·02	46	200	1·66	1·76	+
15·01	90	221	1·95	2·01	+
15·00	120	232	2·08	2·11	+
15·00	154	240	2·19	2·21	+
14·99	210	258	2·32	2·42	+
14·99	258	270	2·42	2·55	+
14·99	226	264	2·35	2·49	−
14·98	300	286	2·48	2·71	+
14·97	406	300	2·61	2·84	+
14·96	522	303	2·72	2·88	+
14·95	624	312	2·80	2·91	+
14·94	765	320	2·88	2·96	+
14·92	880	329	2·94	3·03	+
14·91	1010	343	3·00	3·16	+
14·90	1140	353	3·05	3·21	+
14·89	1247	357	3·10	3·25	+
14·88	1380	362	3·14	3·29	+
14·89	1260	347	3·10	3·17	−
14·90	1110	338	3·05	3·15	−
14·92	900	331	2·95	3·05	−
14·94	770	317	2·89	2·95	−
14·96	486	301	2·69	2·90	−
14·97	396	292	2·60	2·76	−

Series 10.

14·30	0·1	197	$\bar{1}$·00	0·01	?
14·30	1·0	216	0·00	0·43	?
14·30	11·6	247	1·06	1·06	+
14·30	13·3	249	1·12	1·07	+
14·30	9·3	241	0·97	0·91	−
14·30	11·4	247	1·06	1·06	+
14·30	7·3	229	0·86	0·71	−
14·30	5·0	228	0·70	0·70	−
14·30	1·0	215	0·00	0·40	−
14·30	6·5	240	0·81	0·90	+
14·30	6·8	240	0·83	0·90	+
14·30	12·2	255	1·09	1·16	+
14·30	23	266	1·36	1·39	+
14·30	32	274	1·50	1·53	+
14·29	56	281	1·75	1·61	+
14·29	94	294	1·97	1·87	+
14·28	136	305	2·13	2·01	+

Series 10 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
14·28	182	316	2·26	2·16	+
14·28	142	308	2·15	2·06	−
14·29	116	300	2·06	1·92	−
14·29	90	291	1·95	1·82	−
14·30	1·7	210	0·23	0·41	+
14·30	5·0	220	0·70	0·50	+
14·30	7·5	232	0·88	0·76	+
14·30	5·9	215	0·78	0·40	−
14·30	10·0	234	1·00	0·81	+
14·30	6·8	252	0·83	1·14	+
14·30	27	277	1·43	1·13	+
14·30	46	282	1·66	1·67	+
14·30	104	291	2·01	1·82	+
14·28	142	303	2·15	1·95	+
14·28	200	320	2·30	2·21	+
14·27	250	330	2·40	2·35	+
14·26	350	338	2·54	2·46	+
14·25	470	349	2·67	2·62	+
14·24	580	357	2·76	2·72	+
14·22	750	365	2·87	2·80	+
14·22	790	367	2·90	2·83	+
14·20	920	370	2·96	2·87	+
14·20	1030	378	3·01	2·95	+
14·19	1120	381	3·05	3·01	+
14·18	1200	382	3·08	3·03	+
14·17	1300	386	3·11	3·06	+
14·16	1420	395	3·15	3·16	+

Series 11.

13·53	122	305	2·09	1·96	+
13·53	106	269	2·03	1·11	?
13·55	21	257	1·32	0·90	-
13·55	38	286	1·58	1·64	+
13·54	66	302	1·82	1·70	+
13·55	40	273	1·60	1·21	−
13·55	48	291	1·68	1·53	+
13·53	120	325	2·08	2·06	+
13·53	142	325	2·15	2·06	+
13·53	194	342	2·29	2·32	+
13·52	278	356	2·44	2·52	+
13·51	370	365	2·57	2·63	+
13·50	580	380	2·76	2·82	+
13·45	930	403	2·97	3·12	+
13·43	1240	412	3·09	3·22	+
13·44	1110	405	3·04	3·13	−

TABLE V (*continued*).

Series 11 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
13·47	806	390	2·91	2·96	–
13·48	710	388	2·85	2·92	–
13·48	646	375	2·81	2·75	–
13·55	0·7	185	$\bar{1}$·85	$\bar{1}$·28	+
13·55	1·7	224	0·23	$\bar{1}$·68	?
13·55	8·3	229	0·92	0·33	+

Series 12.

12·63	1·0	209	0·00	$\bar{1}$·76	+
12·63	1·2	222	0·08	$\bar{1}$·95	+
12·63	1·0	234	0·00	0·22	+
12·63	3·4	254	0·53	0·64	+
12·63	7·8	280	0·89	1·14	+
12·63	14·6	296	1·16	1·42	+
12·63	17	298	1·23	1·46	+
12·63	6·8	270	0·83	0·95	–
12·63	24	303	1·38	1·54	+
12·63	54	327	1·73	1·93	+
12·62	116	344	2·06	2·19	+
12·62	110	352	2·04	2·31	+
12·61	170	365	2·23	2·49	+
12·61	200	368	2·30	2·53	+
12·61	220	366	2·34	2·51	–
12·60	310	383	2·49	2·73	+

Series 13.

14·02	0·3	168	$\bar{1}$·48	$\bar{1}$·00	+
14·02	<0·2	173	<$\bar{1}$·3	$\bar{1}$·95	+
14·02	<0·25	181	<$\bar{1}$·4	$\bar{1}$·35	+
14·02	1·2	197	0·08	$\bar{1}$·75	+
14·02	1·5	203	0·18	$\bar{1}$·89	+
14·02	2·2	210	0·34	0·05	+
14·02	2·0	207	0·30	$\bar{1}$·99	–
14·02	2·0	240	0·30	0·70	+
14·02	10	258	1·00	0·82	+
14·02	76	292	1·88	1·66	+
14·01	112	312	2·05	1·98	+
14·02	3·4	230	0·53	0·50	+
14·02	9·0	241	0·95	0·72	+
14·02	16	254	1·20	0·98	+

Series 14.

13·86	66	306	1·82	1·83	+
13·86	120	320	2·08	2·05	+

Series 14 (*continued*).

c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.
13·85	140	315	2·15	1·90	+
13·85	186	332	2·27	2·23	+
13·83	350	350	2·55	2·48	+
13·81	570	361	2·76	2·63	+
13·81	510	362	2·71	2·64	+
13·80	660	370	2·82	2·74	+
13·79	770	376	2·89	2·82	+
13·78	870	379	2·94	2·85	+
13·77	960	382	2·98	2·90	+
13·76	1079	387	3·03	2·96	+
13·75	1210	391	3·08	3·00	+
13·74	1300	394	3·11	3·04	+
13·73	1420	400	3·15	3·10	+
13·74	1320	395	3·11	3·05	–
13·75	1220	392	3·08	3·02	–
13·76	1080	388	3·03	2·97	–
13·77	1000	384	3·00	2·92	–
13·78	900	383	2·95	2·89	–
13·79	760	376	2·88	2·82	–

Series 15.

8·04	1·7	240	0·23	0·30	+
8·04	6·0	265	0·78	0·79	+
8·04	27	300	1·43	1·45	+
8·04	17	285	1·23	1·18	–
8·04	12	275	1.08	1·01	–
8·04	20	294	1·30	1·35	+
8·03	66	323	1·82	1·83	+
8·03	116	336	2·06	2·03	+
8·02	186	347	2·27	2·20	+
8·01	270	365	2·43	2·45	+
7·99	450	378	2·65	2·63	+
7·98	550	386	2·74	2·74	+
7·97	650	390	2·81	2·79	+
7·96	780	395	2·89	2·85	+
7·95	880	400	2·94	2·92	+
7·94	990	406	2·99	2·99	+
7·93	1140	412	3·06	3·06	+
7·92	1300	417	3·11	3·12	+
7·90	1460	421	3·16	3·17	+

Series 16.

1·86	16	260	1·20	0·71	?
1·86	23	275	1·36	1·01	+

TABLE V (*continued*).

Series 16 (*continued*).						*Series* 17.					
c.	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes.	*c.*	*p.*	*t.*	Log *p.*	Log $p_{calc.}$	Notes
1·86	32	280	1·51	1·09	+	0·82	39	332	1·59	1·67	+
1·86	37	284	1·57	1·17	+	0·82	14	269	1·15	0·59	−
1·85	72	312	1·86	1·66	+	0·82	25	315	1·40	1·40	+
1·85	120	338	2·08	2·06	+	0·82	40	326	1·60	1·58	+
1·84	180	352	2·26	2·27	+	0·81	120	370	2·08	2·22	+
1·83	280	368	2·45	2·50	−	0·80	190	380	2·28	2·36	+
1·82	380	375	2·58	2·59	+	0·79	260	388	2·42	2·46	+
1·81	490	385	2·69	2·72	+	0·78	340	400	2·53	2·62	+

The interpretation of the vapour-pressure (*pct*-) surface found offers some difficulties. At any given temperature (below a certain critical temperature θ, discussed below) the vapour-pressure falls continuously with loss of water until only about 12 mols. per unit cell are left. As this water content is approached, the isohydric curves get closer and closer together, while the isothermals gradually become parallel to the pressure axis. From about 12 to somewhere between 1·8 and 0·9 mols. water per unit cell, the vapour-pressure remains constant within the accuracy of measurement, then falls off with further dehydration.

TABLE VI. The constants of the vapour-pressure surface of natrolite.

(The molecular heats of hydration * (Q), the integration constants, A, of the equation $\log_{10}p = A - Q/RT(\log_e 10)$, and the temperatures ($\theta$) at which the isohydric curve for fully hydrated natrolite cuts the isohydric curves for natrolites of lower degrees of hydration.)

Mols. water per unit cell.	Q, cals.	A.	θ.
16·00	$7·05 \times 10^3$	6·14	174° C.
15·55	8·47	6·75	220
15·30	10·05	7·25	310
15·17	12·22	7·76	390
15·05	14·42	8·50	420
15·00	15·07	8·63	430
14·30	23·16	10·92	480
14·02	24·34	11·10	490
13·87	24·67	11·21	492
13·55	25·08	11·24	497
12·63	25·90	11·31	511
8·04	25·86	11·31	520
1·86	25·85	11·30	520
0·82	$25·85 \times 10^3$	11·00	ca. 800

* Heats of hydration per gram-molecule of water, for the combination of natrolite with water-vapour (*not* liquid water), and excluding the external work involved.

Now if there were a sharp break in the gradient of the isothermals at 12 mols. water, the vapour-pressure then remaining constant till all the water were removed, the interpretation would offer no difficulties; it would be evident that at 12 mols. water a discontinuity entered, a second, anhydrous solid phase appearing. Natrolite with less than 12 mols. water per unit cell would in that case be

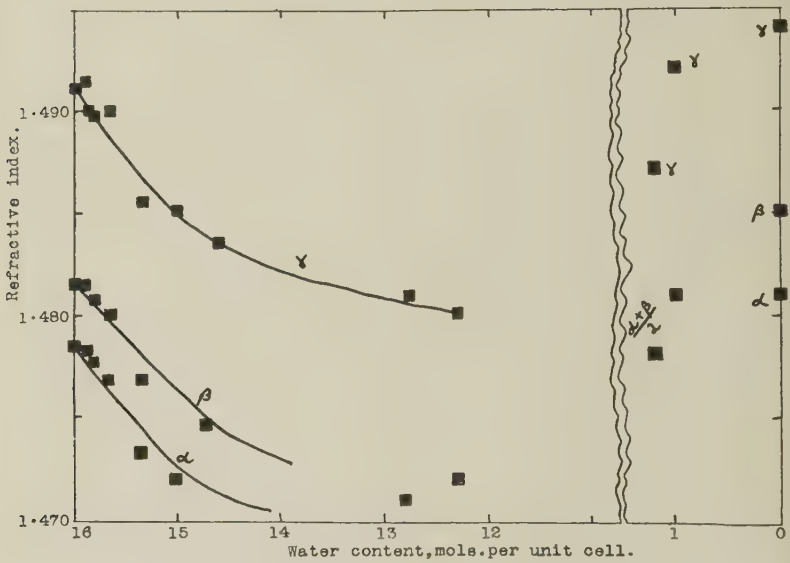

Fig. 10. The variation of the refractive indices of natrolite (for Na-light) with the degree of hydration.

heterogeneous, a mixture of an anhydrous phase and a phase with 12 mols. water per unit cell.

Such an interpretation seemed possible at first, but facts have since been found which discountenance it. Careful study of the *pct*-surface seems to indicate that there is no discontinuity of gradient at any point. There appears to be a definite fall in vapour-pressure at constant temperature when the water content falls below about 0·9 mols. per unit cell.[1] Also X-ray photographs of natrolite dehydrated at 300–350° C. and of anhydrous ammonium natrolite have failed to reveal any marked change such as would be expected if the anhydrous substance were a different phase from natrolite (see further under

[1] This may in part be due to adsorptive effects; but the differences seem to the author too definite to be accounted for in that way.

metanatrolite, below). On the other hand, several cut plates, when partially dehydrated, appeared non-homogeneous, if the loss of water exceeded about 4 mols. per unit cell, opaque, porcellaneous patches appearing. But if the isothermals are really only approximately parallel to the pressure axis, such an effect is still very likely to occur, for it is quite possible that one part of the plate may lose more water than another if the difference in vapour-pressure produced by the excess loss is only very small. Such a state would not be in equilibrium, but the re-establishment of true equilibrium would take an exceedingly long time.

The peculiar course of the isobaric dehydration curves made it quite impracticable to obtain homogeneous material with water contents between 12 and 1 mols. per unit cell, so that the optical continuity between natrolite and anhydrous metanatrolite could not be tested. But a number of experiments were made with several large polished plates of the Benallt material. These were weighed, partially dehydrated, and the refractive indices determined with a total reflectometer. The results, shown in Table VII and in fig. 10, show a marked fall in the refractive index with the loss of the first four molecules of water. If, as seems probable, there is optical continuity between natrolite and anhydrous metanatrolite, this must be followed by a rise during the later stages of dehydration.

TABLE VII. Effect of dehydration on the optical properties of natrolite. All measurements made for sodium-light.

Mols. water per unit cell.	α.	β.	γ.	2E.
16·00*	1·4784	1·4816	1·4911	100° 32′
15·88	1·4782	—	1·4900	100 12
15·90	1·4780	1·4816	1·4903	102 9
15·79	1·4777	1·4808	1·4897	101 29
15·88	1·4780	1·4810	1·4915	—
15·66	1·4768	1·4800	1·4900	100 28
15·34	1·4733	1·4768	1·4856	98 43
15·30	1·4741	1·4777	1·4865	—
15·00	1·472	—	1·485	—
14·70	1·4715	1·4746	1·4838	97 0
12·77	1·471		1·481	—
12·3	1·472		1·480	—
1·0	1·481		1·492	—

*Assumed

The isohydric curves (fig. 8) show no intersection with the vapour-pressure curve of water, indicating that, unlike thomsonite, fully

hydrated natrolite is stable in presence of liquid water at all temperatures. But the isohydric curve of fully hydrated natrolite intersects the others, a new phenomenon not met with in thomsonite, and of some theoretical interest. The data are not sufficiently accurate to be certain of the exact intersection points, but there can be no doubt of their existence and approximate position. The temperatures (θ) at which the vapour-pressure curve of fully hydrated natrolite cuts the curves for natrolite with various lower degrees of hydration are included in table VI and fig. 9.

This intersection of the isohydric curves has a bearing on the theory of mixed crystals. Regarded from a purely phase-rule point of view, one would conclude that when a homogeneous natrolite crystal with, say, $15\frac{1}{2}$ mols. water per unit cell (on the average) was heated, its vapour-pressure being continually balanced by a water vapour-pressure to prevent dehydration, nothing should happen until its vapour-pressure reaches that of fully hydrated natrolite, at about 230° C. and 1000 mm. Hg; at a higher temperature, it should break down into a mixture of two phases, fully hydrated natrolite, and natrolite of that water content which has, at the temperature in question, the same vapour-pressure as the fully hydrated material; at a suitable temperature (about 430° C.), the second phase would correspond to natrolite with $15H_2O$. But, regarded from a microscopic point of view, a natrolite crystal with $15\frac{1}{2}$ mols. water per unit cell is already such a mixture, some unit cells containing 16 mols. H_2O, while others contain only 15, and possibly some even less; clearly, those forces, not as yet fully understood, which interpose to average out the vapour-pressure effects of the individual unit cells in a zeolite with a fractional average unit-cell content of water, become less effective with rise of temperature, and finally the fully hydrated unit cells exert their full effect independently of the others. Yet there seems no reason to suppose that the essential nature of the zeolitic structure, the isomorphism and formation of mixed crystals between different hydrates, should be affected, or that the optical homogeneity of natrolites with water contents less than 16 mols. per unit cell should be lost. We seem here to be finding something intermediate between the zeolitic and the 'normal' hydrate, showing the constancy of vapour-pressure during dehydration characteristic of the latter with the optical continuity characteristic of the former. It is unfortunate that the temperature and pressure at which this phenomenon would appear to occur in natrolite are so high; it is to

be hoped that further work will reveal compounds in which such behaviour occurs at more accessible temperatures and pressures, enabling a proper study of it.

It has proved possible to make a direct determination of the mean molecular heat of hydration of natrolite, thereby obtaining a check on the vapour-pressure surface. The slope of the isohydric lines at any degree of hydration, as explained in Part II of this series, gives the molecular heat of hydration for that degree of hydration, and the mean value is readily computed by the aid of fig. 9, for comparison with the direct determination. The method employed for the measurement was simple, and though not very accurate (lack of proper apparatus prevented a more accurate determination), was sufficient for the purpose. A large platinum crucible was partially filled with water, and supported with corks inside a heat-insulating arrangement of two beakers separated by cotton-wool packing. A quantity of natrolite (8·919 grams) was dehydrated at 400° C., and after cooling and weighing emptied into the water in the crucible, which was at once covered with an insulating lid of cork and cotton-wool, bearing a thermometer. In three minutes the temperature rose 13·2° C., remained constant for two minutes, and then began to fall. The cooling rate was observed, and the extrapolated temperature rise for perfect insulation estimated at 14·3° C. Allowing for the water-equivalents of the crucible and natrolite (the specific heat of natrolite, according to J. Joly (1887), is 0·2375), the material heated was equivalent to 30·16 grams of water, making the heat evolved 452 cals.; as the water expelled was 0·6594 gram, this gives a mean heat of hydration of 12,300 cals. per gram-molecule of water for the reaction with liquid water. Adding the molecular latent heat of water-vapour at 20° C. (10,500 cals.) we have for the directly determined mean molecular heat of hydration of natrolite by water-vapour, 22,800 cals., against 24,000 cals. calculated from the isohydric curves (both for hydration from 4 mols. water per unit cell to full hydration). These figures are all exclusive of the external work.

Considering the approximate nature of the calorimetric work, this is an excellent agreement, and forms a valuable confirmation of the accuracy of the vapour-pressure work. The calorimetric value is probably rather low, for an experiment on the cooling rate of the crucible and its contents, after replacing 5 grams of the water by practically boiling water, showed that the cooling during the first

two hours after the addition of the natrolite was abnormally slow; clearly there must have been a further evolution of heat going on. It is very difficult to estimate the amount of heat evolved in this second period, but it was probably roughly 50 cals., which would almost exactly account for the difference, leading to a value of 24,200 cals. for the calorimetric figure.

It may be mentioned that G. Friedel [1] appears to have been the first to compute a heat of hydration for one of the zeolites; he computed the heat of hydration of analcime at several degrees of hydration from a few isobaric dehydration curves, but could not check his results by direct measurement.

Base-exchange.

Natrolite was one of the first zeolites to receive attention from the base-exchange point of view; H. Eichhorn (1858) treated it with a 4 % solution of calcium chloride, and found no appreciable reaction after ten days at the ordinary temperature. The numerous experiments of J. Lemberg (1876, 1887, 1888) are not of much use, since the products were not invariably crystalline or homogeneous, and were not optically examined. He found a fairly ready exchange with potassium carbonate solution at 100° C., but calcium chloride gave very little reaction. S. J. Thugutt (1894) worked on the same lines. K. Dalmer (1878) treated natrolite with dilute ferrous sulphate solution at room-temperature, and obtained a pale bluish-green product containing ferrous oxide, but in view of subsequent work it seems probable that there was no true base-exchange. F. W. Clarke and G. Steiger (1900) found very considerable base-exchange with 10 % silver nitrate solution at 120° C., half the sodium being replaced in 18 hours. R. Gans (1905) obtained a small but appreciable base-exchange with ammonium chloride solution in two days at room-temperature. H. Kappen and B. Fischer (1928) found that ferrous, ferric, copper, and aluminium chlorides all caused decomposition rather than base-exchange. Dilute (N/10) hydrochloric acid they found to remove sodium and aluminium concurrently and in about equal atomic proportions.

None of these workers made any observations on the optical properties of their products except S. J. Thugutt, who obtained a compound $K_2Al_2Si_3O_{10}.2H_2O$ by heating natrolite with 1% caustic potash solution at 200° C.; he describes the product as being in part needles

[1] G. Friedel, Bull. Soc. Franç. Min., 1898, vol. 21, p. 5.

with straight extinction, in part globulites and pseudomorphs after the natrolite, with weak birefringence. Much alumina and silica went into solution.

J. Koenigsberger and W. J. Müller (1921), on the other hand, made an optical study of natrolite from Böhmisch-Leipa before and after treatment with 25% KCl solution for 24 hours at 180° C., and found that although 14·96% K_2O had been taken up, no effect on the refractive index or birefringence could be measured.

A quite different technique of base-exchange was discovered by E. A. Schneider and F. W. Clarke (1893), and further investigated by F. W. Clarke and G. Steiger (1900) and G. Steiger (1905). Schneider and Clarke found that when natrolite is heated with dry ammonium chloride at 350° C. till all the ammonium chloride has volatilized, the residue contains common salt, up to two-thirds of the sodium of the natrolite being removed in this way. Clarke and Steiger modified this process, heating natrolite with dry ammonium chloride in a sealed tube at 250–300° C., and found that the product is anhydrous $(NH_4)_2Al_2Si_3O_{10}$. G. Steiger (1905) also heated natrolite with fusions of silver or thallous nitrate at 250–300° C., and replaced almost the whole of the sodium by silver (in 22 hours) or by thallium (in 48 hours); the thallous product was practically anhydrous, but the silver natrolite had the normal water content.

The author's experiments were directed to three main ends—the proof that the base-exchange products still retain the natrolite structure, the measurement of some of their physical properties, and an attempt (which did not succeed) to produce mesolite or scolecite by the action of calcium chloride on natrolite. It has been generally assumed, from their close similarity in angles and habit, and from J. Lemberg's indirect preparation from natrolite (via a potassium compound) of a product having the composition of scolecite, and from mesolite and scolecite of products having the composition of natrolite, that natrolite, mesolite, and scolecite are closely related in structure (at one time, indeed, they were commonly regarded as isomorphous). But this assumption rests on no secure foundation, and, while quite probably correct, requires testing by an X-ray study of all three zeolites.

Natrolite digested with a boiling solution of calcium chloride for 700 hours gave no appreciable base-exchange, and attacked the glass flask somewhat; the product retained the same optical properties as the original natrolite. Copper acetate and barium chloride solutions

also gave no appreciable base-exchange in 700 hours at the boil, while potassium chloride attacked the glass very considerably.

Natrolite digested for 4 months with cold copper acetate solution was coated with copper oxide, and showed no signs of base-exchange, but digestion with calcium and potassium chlorides and silver nitrate gave considerable base-exchange. The products were analysed and their optical properties and specific gravities determined, with the results shown in table VIII. The material treated with calcium chloride showed no trace of mesolite or scolecite under the microscope, and had about the same composition as the most calciferous natrolites known. Possibly further digestion might result in the production of some mesolite or scolecite; a digestion for a year or more is being undertaken. No effect of the calcium substitution on the refractive indices could be detected (accuracy $\pm 0{\cdot}002$). Nor was there any sign that calcium substitution is accompanied by an increase in the water content (several workers have assumed that this substitution is to be interpreted as a replacement of Na_2 by $Ca.H_2O$, giving a mixed crystal of natrolite and scolecite molecules). The potassium and silver products also were homogeneous, crystalline, and orthorhombic.

The most satisfactory results, however, were obtained by Steiger's method; natrolite was heated with fusions of ammonium nitrate and potassium thiocyanate at 170–190° C., and with fusions of silver nitrate, thallous nitrate, and lithium nitrate at 230–250° C. for 48 hours, then leached and well washed with hot water, and the air-dry products examined (see table VIII).[1] Nearly pure lithium, silver, potassium, ammonium, and thallous natrolites were thus obtained. As was to be expected, the substitution of potassium, silver, or thallium increases the specific gravity, while lithium and ammonium lower it. Lithium, silver, thallium, and ammonium increase the refractive index, while potassium affects it little if at all. These products also were all homogeneous and crystalline. The optic orientation is the same, and the

[1] For the analysis of the ammonium natrolite, the following method was used. Silica, alumina, and soda were determined on one portion in the usual way. A second portion was weighed into a dried Penfield tube, into the upper bulb of which a quantity of hydrochloric acid (15 %) was then weighed. On ignition of the natrolite, both water and ammonia were expelled, and collected in the bulb containing the acid. The natrolite bulb was cut off, the tube plus acid, ammonia, and water weighed, then the ammonium chloride solution washed out, and the tube dried and weighed. The ammonia in the solution was determined as platinichloride. From these data both ammonia and water are readily calculated.

TABLE VIII. Experiments on base-exchange, with Salesl natrolite.

Treatment.		None.	Digested 4 months at room-temperature with a solution of:			Fused at 200° C. (except $LiNO_3$ and $TlNO_3$, these at 250° C.), with: *				
			KCl.	$AgNO_3$.	$CaCl_2$.	$LiNO_3$.	KCNS.	NH_4NO_3.	$AgNO_3$.	$TlNO_3$.
Percentage composition.	SiO_2	47·38	45·71	43·65	45·40	50·05	43·05	52·76	32·44	24·14
	Al_2O_3	27·63	26·76	28·13	27·79	30·72	25·46	31·44	18·21	15·17
	Na_2O	14·96	11·71	13·54	14·28	4·68	1·94	1·36	1·31	[3·50] §
	R_2O †	—	6·38	6·59	3·48	6·55	19·40	14·39	41·23	52·23
	H_2O	9·58	9·14	8·56	9·35	8·82	9·88	0·32	5·44	4·96
	Total	100·50‡	99·70	100·47	100·30	100·82	99·73	100·27	98·63	[100·00]
Oxygen %		42·31	41·17	40·25	41·82	45·48	38·82	47·51	29·44	22·87
Oxygen, atoms per unit cell. ‖		80·94	77·70	—	78·54	79·24	79·82	79·74	80·00	79·68
Atoms per unit cell, assuming oxygen 80.	Si	23·84	24·05	22·99	23·06	23·25	23·69	23·58	23·80	22·49
	Al	16·38	15·85	17·47	16·64	16·83	16·51	16·57	15·74	16·66
	Na	14·59 ¶	11·95	13·82	14·06	4·21	2·07	1·17	1·86	6·31
	R†	—	4·29	1·80	1·89	12·29	13·64	14.81	15·68	13·78
	H_2O	16·08	16·00	15·04	15·83	13·66	18·13	0·48	13·32	15·40
Specific gravity		2·245	2·21(?)	Varies	2·20	2·135	2·365	2·073	3·09	3·92
Refract. Indices, Na-light.	α	1·479	1·478	Varies	1·478	1·489	1·480	1·507**	1·577	1·620**
	β	1·482	1·481	,,	1·481	1·492	1·483	—	—	—
	γ	1·491	1·488	,,	1·490	1·501	1·490	1·515	1·585††	1·629
Cell-sides, in Å.	a	18·31	—	—	—	17·95	—	18·0	18·59	—
	b	18·66	—	—	—	18·55	—	18·4	18·92	—
	c	6·60	—	—	—	6·47	—	6·55	6·60	—
	d‡‡	2·92	—	—	—	—	2·95	—	—	2·98
	r ‖‖	0·98	1·33	1·5?	0·98	0·68	1·33	1·44	1·5?	1·7?

* The fusion was continued (intermittently) for 48 hours, except for the $AgNO_3$ sion, which was continued for 96 hours, and after leaching and thorough washing the sidue was digested with hot water for 12 hours, and then air-dried.

† R indicates the kation of the salt employed in the base-exchange treatment.

‡ Including 0·41 % K_2O and 0·54 % CaO.

§ By difference.

‖ Assuming no change in the cell-sides in the preparations of columns 2 and 4.

¶ Also 0·26 atom K and 0·29 atom Ca.

** Mean of α and β.

†† Mean of β and γ.

‡‡ Spacing measured from the powder photograph (in Å.). Corresponds to the mean the unresolved diffractions (531), (351), (222), (260), and (620).

‖‖ Radius of the kation introduced by base-exchange, in Å. (In the case of natro- e itself, of sodium.)

birefringence approximately the same as in natrolite for all these derivatives except the silver compound. The latter has $\alpha \perp c$ (001), whereas with all the others it is γ that has this direction. The silver compound is probably optically negative.

The ammonium compound was anhydrous, in agreement with Clarke and Steiger's results, but the thallous compound was found to be hydrated, although base-exchange had gone to about the same extent as in Steiger's experiments. The amount of material prepared was insufficient for a study of its vapour-pressure, but it is to be expected that this would be much higher than that of natrolite, the water being presumably only loosely held.

An X-ray study of these base-exchange products was made by Mr. F. A. Bannister. The ammonium, lithium, and silver compounds, which were coarsely crystalline, were examined by the Laue and rotating crystal methods; but the potassium and thallous derivatives were crystalline powders, only suitable for powder photographs, although their preparation had been carried out with material as coarse as that used for the other two derivatives.

The powder photographs of the potassium and thallous compounds showed a strong general resemblance to a natrolite powder photograph, and there can be little doubt of their structural correspondence, though owing to the complexity of the photographs, it was quite impossible to index them. Only in a few cases could one be certain which were corresponding lines on the photographs; but there are very distinct changes in the intensity of some of the diffractions, particularly with the thallous compound.

One line which could be identified without difficulty on the powder photographs was that given by (531), (351), (222), (260), and (620). Though really a compound line (the spacings of the five planes range from 2·846 to 2·946 Å.), these diffractions were not resolved, but gave a rather wide line, the centre of which could, however, be measured with considerable accuracy. The results are included in table VIII, and it will be seen that the introduction of potassium results in a decided increase in this group of spacings, while thallium causes a still greater increase. This is in accord with the relative sizes of the sodium, potassium, and thallous ions (see further below).

The figures given in table VIII for the oxygen atoms per unit cell for the potassium and thallous natrolites are calculated on the assumption that the introduction of these ions does not alter the c spacing,

while the a and b spacings are assumed to have increased in the same proportion as the above complex of spacings. The agreement with the theoretical figure (80) is remarkably good, even with the thallous natrolite, where the introduction of the thallium atom, much larger and nine times as heavy as sodium, has raised the density by 80 %, to 3·92, and enlarged the cell by some 4 %; although it contains 52 % thallous oxide, this compound is still a true natrolite.

The lithium, silver, and ammonium derivatives gave much coarser crystals, from which rotation photographs could be obtained. As was to be expected from the relative sizes of the sodium and lithium ions, the lithium compound has a considerably smaller unit cell than natrolite, while the silver ion, probably larger than sodium, gives rise to a compound with a larger cell.

The ammonium natrolite was anhydrous, and the loss of water counteracted the introduction of the large ammonium ion, the cell being considerably smaller than that of natrolite; the change was mainly in the a- and b-axes. A good Lauegram of ammonium natrolite, along the c-axis, was also obtained, but this furnished no additional information.

There were considerable changes in the intensity of many diffractions on these rotation photographs, but owing to their complexity but few spots could be indexed. A study of the changes consequent on the base-exchange would be of considerable interest, but would require numerous oscillation photographs to identify the diffractions, and time was not available for this.

The contraction of the unit cell consequent on the replacement of sodium by lithium is 4·7 %, while the replacements by potassium, silver, and thallium result in expansions of 1·8 %, 2·9 %, and 4·0 % respectively. There is general agreement as to the ionic radii of $Li^{\cdot}$, $Na^{\cdot}$, $K^{\cdot}$, and $NH_4^{\cdot}$, which W. H. Zachariasen [1] gives as 0·68, 0·98, 1·33, and 1·44 Å. respectively, values which have been adopted in table VIII. But the atomic radii of $Ag^{\cdot}$ and $Tl^{\cdot}$ are in some doubt. R. W. G. Wyckoff [2] gives $Ag^{\cdot}$ 0·97 and $Tl^{\cdot}$ 1·50 Å., but L. Pauling [3] gives $Ag^{\cdot}$ 1·26 Å. The present data go to show that this last value is probably nearer the truth. Certainly Wyckoff's radius for $Ag^{\cdot}$ is much too low, and the relative cell-sizes of potassium and silver natrolites suggest that Pauling's figure is also low.

[1] W. H. Zachariasen, Zeits. Krist., 1931, vol. 80, p. 137.
[2] R. W. G. Wyckoff, The structure of crystals. New York, 1931, p. 192.
[3] L. Pauling, Zeits. Krist., 1928, vol. 67, p. 377.

The mechanism of the change of cell-size is presumably by a change in the angle θ of Pauling's natrolite structure model (1930), the silicon-aluminium chains turning about the c-axis.

A property of the zeolites which probably has some relation to base-exchange is their electrical conductivity. In so far as this is electrolytic in nature, it must be largely governed by the same forces as control the base-exchange reactions. A. Günther-Schulze (1914), indeed, has concluded that there is a direct proportionality between the electrical conductivity and the initial base-exchange velocity provided the cations are being replaced by others of the same valency. His simple equations can hardly be truly valid, for the relative sizes of replaced and replacing ions must have a considerable influence on the velocity of base-exchange. But his measurements and those of O. Weigel (1923) are in such marked disagreement that much more work is evidently necessary before valid conclusions can be drawn. The author has repeated Günther-Schulze's diffusion constant measurements, by the same method as he used, but has failed to obtain noticeable base-exchange in three weeks. Günther-Schulze's figures must therefore be in error, his conductivity and rate of base-exchange being much too high. Further experiments are in progress on the rate of base-exchange.

Metanatrolite.

In 1890 F. Rinne observed that when crystals of natrolite are heated until they become white and opaque and then cleared in oil, they show, in sections perpendicular to the elongation, a division into sectors, which extinguish at 15° to one another. On exposure to moist air, this metanatrolite, which is clearly monoclinic, absorbs water and is re-converted into natrolite. Its optical orientation is near that of natrolite, the positive acute bisectrix being parallel to the elongation, as in natrolite, while the obtuse bisectrix makes an angle of $7\frac{1}{2}°$ with the face (010) of the usual natrolite orientation (in natrolite it is parallel to (010)).

A. Cavinato (1927) confirmed these results, and found the optic axial angle, 2V, to be about 62°. He also took Lauegrams of natrolite and metanatrolite, through (110), and Debyeograms, but could observe no differences. C. H. Slonim (1930) also found no differences between Debyeograms of natrolite and metanatrolite (dehydrated at 00° C.).

The author has repeated Rinne's experiments, and finds that de-

hydration over a bunsen burner at a temperature of about 400–600° C. produces metanatrolite, with precisely the properties described by Rinne and Cavinato. Its refractive indices are α 1·483, β 1·485, γ 1·494; the positive acute bisectrix is parallel to the elongation, with 2E about 100°; the sectors visible on cross-sections extinguish at 15° to one another; cleavage fragments give straight extinction. The cleavage of natrolite is retained in metanatrolite. On standing in air, metanatrolite crystals very soon break up into an aggregate of fibres parallel to the elongation (*c*-axis of natrolite).

Dehydration at 290–300° C., on the other hand, gave a product, still containing a little water (presumably about 1–2 mols. per unit cell), with a lower refractive index—α' 1·481, γ 1·492 on one preparation, α' 1·478, γ 1·487 on another—and showing indeed a division into sectors on a basal section, but with an extinction difference of only 1–3°.

These data, together with the vapour-pressure measurements and X-ray work on the symmetry of natrolite, suggest that the transition natrolite $\rightleftharpoons$ metanatrolite is a continuous one, both being really monoclinic. Mr. F. A. Bannister made an X-ray examination of several preparations. Three dehydrated at temperatures from 300 to 350° C. showed no differences from natrolite (rotation photographs about the elongation were taken); special precautions were taken in two cases to avoid re-hydration. Another specimen, dehydrated at 400–600° C. until quite opaque, was cleared in oil and examined optically; it gave the division into sectors, extinguishing at 15° to one another, and all the optical properties of the metanatrolite of Rinne. An X-ray rotation photograph of this crystal about its direction of elongation gave a rather poor photograph, owing to the tendency of the crystals to break up into a bundle of fibres; no definite differences between this photograph and one of natrolite could be observed, but there may very possibly be some slight alterations of intensity, and the cell-sides are probably slightly smaller in metanatrolite than in natrolite. The evidence is therefore decidedly in favour of the view that natrolite is isomorphous with the definitely monoclinic metanatrolite.

If this view is accepted, the 'anomalous' diffractions on the X-ray photographs of natrolite, and the peculiarities of the *pct*-surface, both mentioned above, are readily explained. Natrolite is really monoclinic, with the space-group C_2^3, the symmetry-axis being parallel to the elongation, and the angle β being 90° 0′; it is isomorphous with metanatrolite, which is not an independent species, but merely the

final dehydration product of natrolite, and which has the same symmetry and orientation as natrolite. But the structure shows very marked pseudo-symmetry, approaching very closely to the (orthorhombic) symmetry of the space-group C_{2v}^{19}. With the monoclinic orientation, the usual forms of natrolite become: a (100), b (001), m (101) and ($\bar{1}$01), D (110), e (011), and o (111) and ($\bar{1}$11), and the axial ratio $a:b:c = 2{\cdot}773:1:2{\cdot}827$, $\beta = 90°\,0'$, while the optical orientation becomes: $Bx_a \perp$ (010), positive, axial plane (001).

It cannot be said that these conclusions are definitely proved, but they appear to the author to offer the most reasonable explanation of the results so far obtained. Further work on the matter, by X-ray and vapour-pressure methods, is very desirable.

Summary.

Natrolite is shown by nine new analyses and new X-ray measurements to have a constant Si/Al-ratio and a unit-cell formula of $Na_{16}Al_{16}Si_{24}O_{80}.16H_2O$, in agreement with previous results. $Na_2 \rightarrow Ca$ replacement may occur up to about 4, and $Na \rightarrow K$ replacement up to about 2 atoms per unit cell. Natural etch-figures on natrolite from Benallt, Carnarvonshire (a new locality), show the c-axis to be polar. A detailed study of the optical properties of natrolite has been made. Some observations have been made on the effects of partial dehydration on the optical properties. The vapour-pressure has been studied at various temperatures and degrees of hydration, and several peculiarities observed. The heat of hydration has been measured and shown to be in agreement with the vapour-pressure work. Some experiments have been carried out on the base-exchange of natrolite. An X-ray study of natrolite and metanatrolite, together with the vapour-pressure observations, suggests that natrolite is really monoclinic, with space-group C_2^3, the symmetry-axis being parallel to the elongation (the usual c-axis). But there is very marked pseudo-symmetry, the symmetry very closely approaching that of the orthorhombic space-group C_{2v}^{19}, of which C_2^3 is a sub-group.

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* In the original, by a misprint, 'chaux' appears in the tabulated analysis, but it is clear from the following paragraph that soda was intended. Unfortunately, many authors have failed to notice this, and have taken the analysis for one of scolecite.

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List of Indian meteorites.

(With Plate XII.)

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At the suggestion of, and with much assistance from, Dr. L. J. Spencer, Keeper of Minerals in the British Museum,[1] I have examined and, as far as possible, verified and corrected the recorded places of fall of all reported Indian meteorites. The original records were consulted, and as far as possible the places found on the large scale (usually 1 inch = 1 mile) maps in the India Office. This left a residuum regarding which inquiries were made of District Officers in India, to several of whom I am indebted for useful information which has been embodied in the list.

In this list the falls are entered under their original names in alphabetical order by Provinces in British India, but in one list for all the Indian States, and the positions are indicated on the map (plate XII). The correct names of the places of fall are given in each case, in some only the spelling has required correction in accordance with the Government of India standard system,[2] in others the vernacular name has clearly been mistransliterated, and in many cases the name of the district or province has been changed since the fall. Wherever possible the exact date and time of fall, the latitude and longitude of the place thereof, and its distance from some big place or railway station have been given.

[1] The large series of Indian meteorites preserved in the British Museum includes representatives of 86 of the 106 recorded falls, with many exceptional specimens; e.g. the fine Parnallee stone of 60½ kg. (133 lb.) and the complete Nedagolla iron seen to fall. This is largely due to the help given by the Government of India and the generosity of the Director of the Geological Survey of India, with important contributions also from the Trustees of the Indian Museum of Calcutta and the Asiatic Society of Bengal. A stone of the Benares shower of 1798 was presented to the Collection by Sir Joseph Banks in 1802.
—L. J. S.

[2] Sir W. W. Hunter, The Imperial Gazetteer of India. 26 vols. New edit., Oxford, 1907–1909. New (revised) edit. of vol. 26 (Atlas), 1931.

The list includes the meteorites representing 106 distinct falls. An unusually large number of these are stones, namely 100, there being only four irons (Garhi Yasin, Kodaikanal, Nedagolla, and Samelia) and two stony-irons (Lodran and Singhur). Three of the four irons were seen to fall, there being only one found iron. This striking difference as compared with other countries, such as the United States or Australia, is doubtless accounted for by the fact that a large part of India has been thickly inhabited and cultivated for a very long period, with the consequence that most of the irons have been found long ago and used as metal.

Indian meteorites are also exceptional in that nearly all of them, namely 101, have been actually observed to fall. Of the falls (83) for which the time of day is recorded 68 (81·9%) fell during the 12 hours of daylight (6.0 a.m. to 6.0 p.m.) and only 15 (18·1 %) during those of night. O. C. Farrington ('Meteorites', 1915, p. 41) gives 194 (73·2 %) and 71 (26·8 %) as the corresponding distribution of the 265 falls for the whole world. The monthly distribution of the 97 falls for which the date has been recorded is as follows (one was recorded as in August or September, i.e. in the Hindu month Bhadon):

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12	8	4	12	10	9	3	8·5	8·5	5	9	8

In fig. 1 these numbers, reduced to percentages, are compared with those of O. C. Farrington and of P. N. Chirvinsky. Though differing to some extent there is general agreement, especially in the position of the minima, the chief difference being as regards December and January. The more violent fluctuations of the Indian curve are doubtless due to the smaller total number concerned.

As some guide to the real frequency of falls the following may be of interest. In the United Provinces of the 24 falls which occurred during the century 1831–1930, 12 occurred during the first and the same number during the second half, indicating an intrinsic probability of regular recording. Of the total area of the Province, 107,000 square miles, 11,000 should be deducted for the sparsely populated tracts in the Himalaya and south Mirzapur from which no falls have been recorded. This gives an average of one fall per 4,000 square miles per century, as compared with 94 recorded falls for all India and Burma (1,800,000 square miles) during the same period, or one fall per 19,200 square miles per century. It appears probable,

therefore, that at least 450 falls have not been recorded. If, however, it be assumed that falls are equally likely to occur at night as by day, and that the difference is merely due to non-record of many of the former, a further addition must be made. Taking 25 % as a round figure lying between the percentage of Indian night falls (18·1) and that deduced from Farrington's figures (26·8), this addition would amount to 50 %; so that, assuming all daylight falls to have been recorded in the United Provinces, the number for all India for the century would be 675, indicating that only about 14 % of falls have been recorded.

The United Provinces have been selected as a basis for this estimate as being a compact block of territory, and, with the exception of the omitted area, a level, highly cultivated, and thickly populated (438 per square mile) tract, no part of which is, like much of Bengal, liable to periodic flooding, and which has been under fairly uniform administration throughout the period concerned, where reporting is likely to have been at least as full as anywhere in the world.

ASSAM

1. **Assam.** Stone (brecciated grey chondrite), three pieces, total weight about 2·7 kg., found in Calcutta, 1846, supposed to have come from Assam.

2. **Goalpara.** Stone (ureilite), about 2·7 kg., found 1868, supposed to have fallen at Goalpara, 26° 3′ N., 90° 40′ E.

BENGAL

1. **Dokachi.** Shower of over a hundred stones (spherical chondrite), twenty-four (total weight 3·838 kg.) recovered, fell 22. 10. 1903, 7 p.m., some at Dokachi, 23° 30′ N., 90° 20′ E., 17 miles SW. of Dacca, police station Srinagar, subdivision Munshiganj, district Dacca; and some at Kolapara, Dakhin Paiksha, Hariya, Munshiya, Kukutiya, Bibandi, Bangaon, and Rana, villages from 1 mile WSW. to 6 miles ENE. of Dokachi.

2. **Gopalpur.** Stone (spherical bronzite-chondrite), about 1·6 kg., fell 23. 5. 1865, 6 p.m., at Gopalpur, 22° 40′ N., 89° 50′ E., near police station Bagirhat, pargana Salimabad, district Khulna.

3. **Muraid.** Three stones (white chondrite), two recovered, 4·703 kg., fell 7. 8. 1924, 2.30 p.m., one at Muraid, 24° 30′ N., 90° 13′ E., 24 miles SSW. of Mymensingh, police station Ghatail, subdivision

Tangail, district Mymensingh; the other at Mantala, 1 mile SW. of Muraid.

4. **Pirgunje.** Stone (veined white chondrite), 0·842 kg., fell 29. 8. 1882, at Pirganj, 25° 48′ N., 88° 27′ E., 22 miles NW. of Dinajpur, subdivision Thakurgaon, district Dinajpur.

5. **Rampurhat.** Stone (chondrite), 0·1 kg., fell 21. 11. 1916, 9.30 a.m., at Buripara in Rampurhat town, 24° 10′ N., 87° 46′ E., police station and subdivision Rampurhat, district Birbhum.

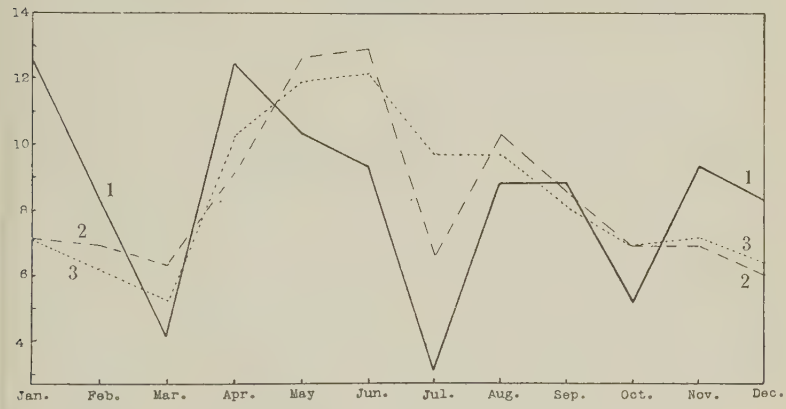

Fig. 1. Percentage curves of monthly falls of meteorites.

(1) 97 Indian falls since 1795.

(2) 350 falls for the whole world tabulated by O. C. Farrington, Times of the fall of meteorites. Amer. Journ. Sci., 1910, ser. 4, vol. 29, p. 211; and 'Meteorites', Chicago, 1915, p. 39.

(3) 422 falls tabulated by P. N. Chirvinsky, Monatstatistik der Meteoritenfälle. Centr. Min., Abt. A, 1926, p. 239.

6. **Shalka.** 'An immense stone, said to have measured 3 feet across', but only 3·5 kg. preserved, fell 30. 11. 1850, 4.30 p.m. 'Shalka' is probably Saluka, 23° 6′ N., 87° 18′ E., near Bhora-Dharmpur, about 10 miles SE. of Bankura, district Bankura.

7. **Shytal.** Stone (brecciated intermediate hypersthene-chondrite), fell 11. 8. 1863, noon. Shytal is said to be in 'the Madhupur jungle, Mymensingh district, 40 miles north of Dacca', i.e. about 24° 21′ N., 90° 30′ E. The District Magistrate of Mymensingh writes (letter dated 4. 7. 32) 'there is no such place in the Madhupur jungle within my knowledge'.

8. **Vishnupur.** Two stones (brecciated intermediate chondrite), fell 15. 12. 1906, 9.30 a.m.: one, 670 g., at Kherai Bani, 23° 6′ N.,

87° 26′ E., the other, 1·767 kg., at Mathura, 6 miles WSW., near Ramsagar, 16 miles SE. of Bankura, subdivision Vishnupur, district Bankura.

BIHAR and ORISSA

1. **Andhara.** A stone, weight about 2·7 kg., fell 2. 12. 1880, 4 p.m., at Andhara or Ujyan, 26° 35′ N., 85° 34′ E., 4 miles NW. of Sitamarhi (police station and subdivision), district Muzzaffarpur. The stone has become an object of worship, so no more is known of it.

2. **Butsura.** Five stones (intermediate chondrite), total weight 27·5 kg., fell 12. 5. 1861, noon, in a tract about 5 miles SW. of Bagaha, 27° 5′ N., 84° 5′ E. (Bengal North-Western Railway), subdivision Bettia, district Champaran. The falls occurred at Piprasi 5 kg., Ballua 140 and 200 g., Chiriya 4 kg., and Jataha Bazar 13 kg., all now in the Gorakhpur district (United Provinces) except Piprasi. Qutahā Bazār in the accounts of this fall is a mistransliteration of Jatahā Bazār, جتہا بزار being misread as قتہا بزار

3. **Manbhoom.** A shower of stones (amphoterite), fell 22. 12. 1863, 9 a.m.; the largest, 1·5 kg., at Govindpur, 23° 3′ N., 86° 42′ E., 2 miles S. of Manbazar and 20 miles SE. of Purulia, district Manbhum, and other portions at the neighbouring villages Pandra and Kashipur.

4. **Nawapali.** Three stones (carbonaceous chondrite), of which only 60 g. recovered, fell 6. 6. 1890, at Nawapali, 21° 15′ N., 83° 40′ E. The Deputy Commissioner of Sambalpur writes (25. 9. 1932) that the village Nawapali is in tahsil Bargarh and is 34 miles SW. of the town Sambalpur, district Sambalpur.

5. **Ranchapur.** A stone, of which four pieces, 366·3 g., recovered, fell 20. 2. 1917, 8.30 a.m., at Ranchapur, 23° 59′ N., 87° 5′ E., 12 miles E. of Jamtara, police station Kundahit, subdivision Jamtara, district Santal Parganas.

6. **Segowlie.** About thirty stones (crystalline chondrite), weights 0·5–13 kg., fell 6. 3. 1853, noon, at Sagauli (Bengal North-Western Railway), 26° 45′ N., 84° 47′ E., 13 miles WNW. of Motihari, district Champaran.

7. **Sherghotty.** A stone (sherghottite), 5 kg., fell 25. 8. 1865, 9 a.m., at police station Sherghati, 24° 33′ N., 84° 50′ E., 20 miles SW. of Gaya, district Gaya.

8. **Shikarpur.** Stone (veined white chondrite), 3·68 kg., fell 9. 8. 1921, 9 a.m., at Diari Shikarpur, 25° 51′ N., 87° 35′ E., 8 miles NW. of Purnea, police station Kasba, district Purnea.

BOMBAY

1. **Bhagur.** Stone (veined white chondrite), fell 27. 11. 1877, 6 p.m., at Bhagur, near Dhulia, 20° 53′ N., 74° 50′ E., district West Khandesh.

2. **Dharwar.** Stone (? intermediate chondrite), 1·8 kg., fell 15. 2. 1848, 1 p.m., at Naglur, 14° 53′ N., 75° 36′ E., 20 miles N. of Ranibennur, taluq Ranibennur, district Dharwar.

3. **Jamkheir.** Two stones (brecciated spherical chondrite), about 4 inches across, but only small fragments recovered, fell 5. 10. 1866, noon, at Jamkhed, 18° 45′ N., 75° 20′ E., taluq Jamkhed, district Ahmadnagar.

4. **Kalumbi** (or Kalambi). Stone (veined white chondrite), about 4·5 kg., fell 4. 11. 1879, at (probably) Kalambha, 17° 50′ N., 73° 59′ E., 16 miles NNW. of Satara, taluq Wai, district Satara.

5. **Manegaon.** Stone (diogenite ; hypersthene-achondrite), about 15 × 5 inches, but only a few ounces recovered, fell 29. 6. 1843, 3.30 p.m. at Manegaon, 20° 58′ N., 76° 6′ E., 20 miles E. of Bhusawal (Great Indian Peninsular Railway), taluq Bhusawal, district East Khandesh.

6. **Singhur.** Stony-iron (? pallasite), 14·2 kg., found 1847 at Sinhgarh, 18° 19′ N., 73° 55′ E., 14 miles SSW. of Poona, district Poona.

BURMA

1. **Quenggouk.** Three stones (spherical chondrite), total weight 6·045 kg., fell 27. 12. 1857, 2.30 a.m., at Kwingauk, 17° 46′ N., 95° 11′ E., township Ngathainggyaung, district Bassein, Lower Burma.

CENTRAL PROVINCES

1. **Bori.** Stone (veined intermediate chondrite), weight 8·6 kg., fell 9. 5. 1894, 4 p.m., at Bori, 21° 57′ N., 78° 2′ E., 12 miles NE. of Badnur, district Betul.

2. **Chandakapur.** Three stones (brecciated intermediate hypersthene-chondrite), 8·9 kg., fell 6. 6. 1838, noon, at Chandakapur or Burgaon-Dewalgaon, (probably) 20° 16′ N., 76° 1′ E., 16 miles SW. of Chikhli, tahsil Chikhli, district Bludana.

3. **Donga Kohrod.** Stone (intermediate chondrite), about 0·45 kg., fell 23. 9. 1899, 3 p.m., at Donga Karaod, 21° 52′ N., 82° 27′ E., 24 miles SE. of Bilaspur, tahsil Janjgir, district Bilaspur. (Letter of Deputy Commissioner, Bilaspur, of 6. 6. 1932.)

4. **Sitathali.** Two stones (grey bronzite-chondrite), 1·6 kg., fell 4. 3. 1875, 11 a.m., at Sitathali, 20° 55′ N., 82° 35′ E., 2 miles from police station Narra, and 62 miles E. of Raipur, tahsil Mahasamund, district Raipur.

MADRAS

1. **Gurram Konda.** Stone (white chondrite), 8 g. recovered, fell 1814, at Gurram Konda, 13° 47′ N., 78° 36′ E., 50 miles NW. of Chittoor, taluq Vayalpad, district Chittoor.

2. **Kakangari.** Two stones (spherical chondrite), 0·34 kg. recovered, fell 4. 6. 1890, 8 a.m., at Kangankarai (Madras Railway), 12° 23′ N., 78° 31′ E., taluq Tirupatur, district Salem.

3. **Kodaikanal.** Iron (fine octahedrite, brecciated), 16 kg., found, 1898, at Kodaikanal, 10° 16′ N., 77° 24′ E., district Madura.

4. **Kuttippuram.** Shower of stones (veined white chondrite), total weight 46 kg., largest 32 kg., fell 6. 4. 1914, 7 a.m., at Kuttippuram (Madras Railway), 10° 50′ N., 76° 2′ E., 34 miles SE. of Calicut, district Malabar. Portions fell from Kuttippuram to the coast at Kutteyi 32 miles SSE. of Calicut.

5. **Nammianthal.** Stone (veined spherical chondrite), 4·5 kg., fell 27. 1. 1886, at Durginammiyandal, 12° 17′ N., 79° 12′ E., 6 miles NE. of Tiruvannamalai, district North Arcot.

6. **Nedagolla.** Iron (nickel-poor ataxite), 4·5 kg., fell 23. 1. 1870, 7 p.m., at Nidigullam, 18° 41′ N., 83° 29′ E., 7 miles S. of Parvatipuram, district Vizagapatam.

7. **Parnallee.** Two stones (veined grey hypersthene-chondrite), 77·7 kg., fell 28. 2. 1857, noon. Parnallee is said to be 16 miles S. of Madura, but the Collector of Ramnad, in which district such a point would now be, writes (letter of 30. 6. 32) ‘ there is no village Parnalle or any place whose name could be so perverted in my district ’. Possibly Perunali, 9° 14′ N., 78° 21′ E., a police station, in the Ramnad district, 52 miles SSE. of Madura is meant, a surmise confirmed by the Geological Survey of India (letter of 15. 9. 32.)

8. **Udipi.** Stone (veined grey chondrite), 3·63 kg., fell April 1866, 10 a.m., at Yedabettur, 13° 29′ N., 74° 47′ E., taluq Udipi, district South Kanara.

9. **Yatoor.** Stone (spherical chondrite), 13·6 kg., fell 23. 1. 1852, 4.30 p.m., at Yetur, 14° 18′ N., 79° 46′ E., 23 miles SW. of Nellore, taluq Rapur, district Nellore. (Letter of 31. 5. 32 from the Collector of Nellore.)

PUNJAB and DELHI

1. **Adhi Kot.** Stone (black chondrite), 4·239 kg., fell 1. 5. 1919, noon, at Adhi Kot, 32° 16′ N., 71° 49′ E., 15 miles N. of police station Nurpur, district Shahpur.

2. **Charwallas.** Stone (intermediate chondrite), 12 kg., fell 12. 6. 1834, 8 a.m., at Chaharwala, 29° 29′ N., 75° 30′ E., 30 miles WNW. of Hissar, tahsil Fatehabad, district Hissar.

3. **Delhi.** Two stones (white chondrite), about 1 kg., fell 18. 10. 1897, 7.30 p.m., near the Kutb Minar, 28° 34′ N., 77° 15′ E., 5 miles SSW. of Delhi.

4. **Dhurmsala** (or Dharmsala). Several stones (intermediate hypersthene-chondrite), largest 150 kg., fell 14. 7. 1860, 2.15 p.m., in Dharmsala, 32° 14′ N., 76° 28′ E., district Kangra.

5. **Jhung** (or Jhang). A shower of stones (spherical chondrite), fell June 1873, 3 p.m., 6 kg. recovered, at Kot diwan 15 miles, Dhuin Muhammad 13 miles, and Dhiraj 11 miles SW. of Jhang, and Talwara 10 miles NW. of Jhang, 31° 18′ N., 72° 23′ E., district Jhang.

6. **Kangra Valley.** Stone (spherical chondrite), 395 g., fell about 1897 in the Kangra valley, about 32° N., 76° 20′ E., district Kangra.

7. **Lodran** (or Lodhran). Stony-iron (lodranite), 1 kg., fell 1. 10. 1868, 2 p.m., 12 miles E. of Lodhran, 29° 32′ N., 71° 48′ E., tahsil Lodhran, district Multan.

8. **Pirthalla.** Stone (brecciated spherical chondrite), 1·36 kg., fell 9. 2. 1884, 2.30 p.m., at (probably) Pirthalla-Lalanda, 29° 35′ N., 76° 0′ E., 38 miles N. by E. of Hissar, police station Tohana, tahsil Barwala, district Hissar.

SIND

1. **Garhi Yasin.** Iron (medium to coarse octahedrite), 380 g., fell Jan. 1917, in night, at Garhi Yasin, 27° 53′ N., 68° 32′ E., 23 miles WNW. of Sukkur, taluq Shikarpur, district Sukkur.

2. **Sindhri.** Stone (spherical chondrite), about 2 kg. seen to fall 10. 6. 1901, 11 p.m., and another stone of 7 kg. dug up a week later, at ‘ Sindhri, near Samo-junejo ’. This is probably Sumo-juneja of the half-inch map, 26° 13′ N., 69° 33′ E., 30 miles NNE. of Khipro, taluq Khipro, district Thar and Parkar.

3. **Visuni.** Stone (crystalline spherical chondrite), 594 g. recovered, fell 19. 1. 1915, noon, at Visuni or Bisoi-jo-thar, 25° 27′ N., 70° 0′ E., 15 miles ENE. of Umarkot, taluq Umarkot, district Thar and Parkar.

UNITED PROVINCES

1. **Akbarpur.** Stone (brecciated grey chondrite), 2 kg., fell 18. 4. 1838, 8 a.m., at Akbarpur, 29° 43′ N., 77° 57′ E., 6 miles S. of Roorkee, tahsil Roorkee, district Saharanpur.

2. **Ambapur Nagla.** Stone (crystalline spherical chondrite), 6·4 kg., fell 27. 5. 1895, 1 a.m., at Ambapur Nagla, tahsil Sikandra Rao, district Aligarh. The Collector of Aligarh writes (letter of 7. 6. 32), 'There is no village in tahsil Sikandra Rao named Ambapur Nagla. The only village with a name resembling it is Amba Madapur, 4 miles north of Sikandra Rao.' This would be at 27° 40′ N., 78° 15′ E.

3. **Atarra.** Three stones (black chondrite), 1·28 kg., fell 23. 12. 1920, 5.35 p.m., at Turra, 25° 15′ N., 80° 38′ E., 4 miles SE. of Atarra (Great Indian Peninsular Railway), tahsil Badausa, district Banda.

4. **Banswal.** Stone (grey chondrite), 14 g. recovered, fell 12. 1. 1913, 6 p.m., at Banswal, a hamlet of Chamarsari village, 30° 24′ N., 78° 12′ E., 10 miles SE. of Mussoorie, district Dehra Dun.

5. **Benares** (or Krakhut). Shower of stones (spherical chondrite), largest recovered 1 kg., fell 19. 12. 1798, 8 p.m., at Krakhaut, 25° 22′ N., 82° 55′ E., 14 miles from Benares, district Benares. [Compare Bishunpur under Indian States.]

6. **Bustee** (or Basti). Stone (aubrite; enstatite-achondrite), 1·7 kg., fell 2. 12. 1852, 10 a.m., at Basti, 26° 47′ N., 82° 50′ E., district Basti.

7. **Chail.** Shower of nineteen stones (brecciated chondrite), some said to be up to 14 kg., but only 0·5 g. recovered, fell 5. 11. 1814, 4.30 p.m., at and near Chail, 25° 22′ N., 81° 40′ E., 14 miles W. of Allahabad, district Allahabad.

8. **Chainpur.** Shower of stones (spherical chondrite), 8 kg. recovered, fell 9. 5. 1907, 1.30 p.m., at and near Chainpur, 25° 51′ N., 83° 29′ E., 20 miles SE. of Azamgarh, tahsil Deogaon, district Azamgarh. Some pieces at Bhikampur and Jalalabad, 3 miles SE. and 3 miles SW. of Chainpur respectively,

9. **Chandpur.** Stone (veined white chondrite), 1·14 kg., fell 6. 4. 1885, at Chandpur, 27° 17′ N., 79° 3′ E., 5 miles N. by W. of Mainpuri, district Mainpuri.

10. **Dandapur.** Two stones (veined intermediate hypersthene-chondrite), 5·6 kg., fell 5. 9. 1878, 5 p.m., at Dandupur, 26° 55′ N., 83° 58′ E., 38 miles ENE. of Gorakhpur, tahsil Padrauna, district Gorakhpur.

11. **Dyalpur.** Stone (ureilite), 280 g., fell 8. 5. 1872, at Dyalpur, district Sultanpur, approximately 26° 14′ N., 82° 12′ E. No further detail is available. The Deputy Commissioner of Sultanpur reports (letter dated 22. 8. 1932) that no such place is traceable in the district, but that there are hamlets such as Pura Dayal, Pura Dayal Singh, and Purwa Dayalapur in various tahsils.

12. **Ekh Khera.** Stone (veined intermediate chondrite), 840 g., fell 5. 4. 1916, 2.30 a.m., at Ekh Khera, 28° 16′ N., 78° 47′ E., 30 miles N. of Budaun, tahsil Bisauli, district Budaun.

13. **Futtehpur.** Shower of stones (veined white chondrite), weights 0·5–2 kg., fell 30. 11. 1822, 6 p.m., over a stretch of country from Fatehpur to Bithur, 5 miles WNW. of Cawnpore, some 70 miles, in districts Fatehpur and Cawnpore; 25° 52′ N., 80° 50′ E., to 26° 25′ N., 80° 20′ E.

14. **Haraiya.** Stone (white to grey chondrite), 1 kg., fell Aug. or Sept. 1878, afternoon, at Haraiya, 26° 48′ N., 82° 32′ E., 14 miles W. of Basti, district Basti.

15. **Kadonah.** 'Large' stone (veined grey chondrite), weight not recorded, fell 7. 8. 1822, in the night, 'at Kadonah in the Agra district'. The Collector of Agra (letter dated 18. 6. 32) writes, 'There is no village named Kadonah in the Agra district. Karondhna is, however, a village in tahsil Fatehabad, district Agra, about 2 miles west of Tharai flag station on the Agra-Bah branch of the Great Indian Peninsular Railway.' This would place the fall at about 27° 5′ N., 78° 20′ E.

16. **Kaee.** Stone (spherical chondrite), about 240 g., fell 29. 1. 1838, at (probably) Kaikhai, 27° 15′ N., 79° 58′ E., 3 miles W. of Sandi, pargana Sandi, tahsil Bilgram, district Hardoi.

17. **Kheragur.** Stone (spherical chondrite), about 500 g., fell 28. 3. 1860, at (probably) Khairagarh, 26° 57′ N., 77° 53′ E., 20 miles SW. of Agra, district Agra.

18. **Khohar.** Stone or ? stones (22 pieces recovered, total weight 9·7 kg.), fell 19. 9. 1910, 1 p.m., at Khohar, 25° 6′ N., 81° 32′ E., 5 miles SSE. of Bargarh (Great Indian Peninsular Railway), tahsil Mau, district Banda.

19. **Kusiali.** Stone (white chondrite), fell 16. 6. 1860, 5 a.m., at Kasiali, 'a village 38–40 miles SW. of Pauri, patti Walla-Udaipur, tahsil Lansdowne, district Garhwal' (letter of Deputy Commissioner, Garhwal, of 14. 6. 32); this would be about 29° 41′ N., 78° 23′ E.

20. **Lalitpur.** Stone (veined intermediate chondrite), 372 g. collected, fell 7. 4. 1887, 10.30 a.m., between Jharaota and Nayagaon, 24° 27′ N., 78° 34′ E., 20 miles SE. of Lalitpur, tahsil Mahroni, subdivision Lalitpur, district Jhansi.

21. **Meerut.** Stone (intermediate chondrite), 22 g. preserved, fell 1860–1862, at Meerut, 29° 1′ N., 77° 48′ E., district Meerut.

22. **Merua.** Shower of stones (grey bronzite-chondrite), total collected 71·4 kg., fell 30. 8. 1920, 11.15 a.m., at and near Merua, 25° 29′ N., 81° 59′ E., 9 miles ENE. of Allahabad, district Allahabad. Portions at the neighbouring villages Chukri, Manpur or Baghai kalan, Mustafabad, and Umri.

23. **Mhow.** Shower of stones (intermediate chondrite), fell 16. 2. 1827, 3 p.m., largest 1·4 kg., at Mau, 25° 54′ N., 83° 37′ E., 30 miles SE. of Azamgarh, tahsil Mau, district Azamgarh.

24. **Mirzapur.** Stone (veined and brecciated intermediate chondrite), fell 7. 1. 1910, 11.30 a.m., 8·5 kg. recovered, at village Mirzapur, 25° 41′ N., 83° 15′ E., 27 miles WNW. of Ghazipur, tahsil Saidpur, district Ghazipur.

25. **Moradabad.** Stone (white chondrite), 70 g. preserved, fell 1808 in Moradabad district. (Moradabad town is at 28° 47′ N., 78° 50′ E.)

26. **Nagaria.** Stone (eucrite), 12 kg., fell 24. 4. 1875, 7.30 a.m., at Nagaria, 26° 59′ N., 78° 13′ E., 19 miles SSE. of Agra, tahsil Fatehabad, district Agra.

27. **Pokhra.** Stone (crystalline bronzite-chondrite), 340 g., fell 27. 5. 1866, 8.30 p.m., at Pokhra, 26° 43′ N., 82° 40′ E., 6 miles ESE. of Basti, tahsil and district Basti.

28. **Sabetmahet.** Stone (crystalline spherical chondrite), 1·25 kg., fell 16. 8. 1885, evening, at Sahet-mahet, 27° 26′ N., 82° 5′ E., 12 miles NW. of Balrampur (Bengal North-Western Railway), tahsil Utraula, district Gonda. Has become an object of worship.

29. **Sultanpur.** Shower of stones (black chondrite), 1·71 kg. collected, fell 10. 7. 1916, 11 a.m., at Sultanpur, 25° 56′ N., 84° 17′ E., 4 miles N. of Bansdih, tahsil Bansdih, district Ballia; portions at near villages Mandiari and Kharauni, 2 miles W. and 3 miles SSE. respectively of Sultanpur.

30. **Supuhee.** Six stones (brecciated grey chondrite), 7·285 kg., fell 19. 1. 1865, noon, at and near Sapahi, 26° 43′ N., 84° 13′ E., 14 miles SSE. of Padrauna, tahsil Padrauna, district Gorakhpur; portions fell near villages Khuria and Babnauli.

INDIAN STATES

1. **Baroti.** Stone (white hypersthene-chondrite), 4·5 kg., fell 15. 9. 1910, 10 a.m., at Baroti, 31° 37′ N., 76° 48′ E., 20 miles N. of Bilaspur, Bilaspur State, Simla Hills.

2. **Bherai.** Stone (veined white hypersthene-chondrite), 100 g., fell 28. 4. 1893, 8 a.m., on coast between Bherai and Jafarabad, 20° 50′ N., 71° 28′ E., Junagarh State, Kathiawar.

3. **Bholghati.** Two stones (howardite), 2·5 kg., fell 29. 10. 1905, 8.30 a.m., at Bholgati, 22° 5′ N., 86° 54′ E., 35 miles N. of Balasore, pargana Deoli, Mayurbhanj State, Orissa.

4. **Bishunpur.** Four stones (black chondrite), 1·039 kg. recovered, fell 26. 4. 1895, 3 p.m., at Bishunpur, 25° 23′ N., 82° 36′ E., 2½ miles SSE. of Bhadohi (East Indian Railway), Benares State, and at Parjapatpur, 1 mile NW. of Bishunpur. In 1895 this locality was in district Mirzapur, North-Western Provinces (since 1902 United Provinces), the Benares State not being constituted until 1911. (Letter of 26. 7. 32 from the Collector of Mirzapur, United Provinces.) [The Benares fall of 1798 was near the city of Benares, district Benares, United Provinces.]

5. **Cranganore** (or Changanorein). Stone (grey chondrite), 1·46 kg., fell 3. 7. 1917, 12.45 p.m., at Kranganur (or Kodungalur), 10° 12′ N., 76° 16′ E., 14 miles N. of Cochin, Cochin State.

6. **Durala.** Stone (veined intermediate hypersthene-chondrite), 13 kg., fell 18. 2. 1815, noon. It is said to have fallen at Durala, 30° 20′ N., 76° 41′ E., 17 miles from Ambala in Patiala State. The one-inch map shows no such village, but there are two villages Surala kalan and Surala khurd, at 30° 18′ N., 76° 38′ E., 13 miles S. by E. of Rajpura (North-Western Railway). Durālā is probably a mistransliteration of Surālā, دُرالا for سُرالا

7. **Gambat.** Stone (veined intermediate chondrite), 6·5 kg., fell 15. 9. 1897, at Gambat, 27° 21′ N., 68° 32′ E. (36 miles SW. of Sukkur), Khairpur State.

8. **Haripura.** Shower of stones (carbonaceous chondrite), two recovered, one weighed 315 g., fell 17. 1. 1921, 9 p.m., at Haripura, near police station Pilod, 28° 23′ N., 75° 47′ E., nizamat Jhunjhunu, Shekhawati, Jaipur State, Rajputana.

9. **Jajh deh Kot Lalu.** Stone (veined crystalline chondrite), 973 g., fell 2. 5. 1926, between 5 and 6 p.m., at Jajhdeh-kot-lalu, 26° 45′ N.,

68° 25′ E. (22 miles SSE. of Naushahro), taluq Faizganj, Khairpur State.

10. **Judesegeri.** Stone (spherical chondrite), 680 g. recovered, fell 16. 2. 1876, evening, at Judesegeri, 12° 51′ N., 76° 48′ E., 37 miles SW. of Tumkur, taluq Kadaba, district Tumkur, Mysore State.

11. **Kamsagar.** Stone (intermediate chondrite) 1·293 kg., fell 12. 11. 1902, 1 p.m., at Kamsagar, 14° 11′ N., 75° 48′ E., 35 miles NE. of Shimoga, taluq Channagiri, district Shimoga, Mysore State.

12. **Karkh.** Several stones (grey chondrite), 22 kg. recovered, fell 27. 4. 1905, 1 p.m., in the neighbourhood of Karkh, 27° 48′ N., 67° 10′ E. (65 miles W. of Larkhana), Jhalawan State, Baluchistan. Portions fell below the Sumbhaji hills, and at Michara, 4 and 5 miles respectively WNW. of Karkh, and near Nar on the Mula pass.

13. **Khairpur.** Shower of stones (crystalline enstatite-chondrite), total weight recovered 13·6 kg., fell 23. 9. 1873, 5 a.m., over area 16 × 3 miles near Khairpur, 29° 32′ N., 72° 18′ E., 30 miles ENE. of Bahawalpur, Bahawalpur State. Portions also fell at Mailsi, tahsil Mailsi, district Multan, Punjab.

14. **Khetri.** Shower of about forty stones (brecciated grey bronzite-chondrite), 8 kg. found, but very little preserved, fell 19. 1. 1867, 9 a.m., mostly at Saonlod, 28° 1′ N., 75° 49′ E., 3 miles N. of Khetri, Shekhawati, Jaipur State, Rajputana.

15. **Lakangaon.** Stone (eucrite), 212 g., fell 24. 11. 1910, 6 p.m., at Lakangaon, probably 21° 52′ N., 76° 2′ E., pargana Bhikangaon, district Nimar, Indore State, Central India; 25 miles W. by N. of Khandwa (Great Indian Peninsular Railway).

16. **Lua** (or Dabra). Shower of stones (grey chondrite), 9·241 kg. recovered, fell 26. 6. 1926, 4.30 p.m., at Dabra, 24° 55′ N., 75° 8′ E. (34 miles NNE. of Nimach), pargana Nandwas, Indore State, Central India, and at Lua and Dongria, pargana Begu, Udaipur State, villages a mile or two distant from Dabra. [Min. Abstr., **4**–118.]

17. **Moti-ka-nagla.** Shower of stones (crystalline chondrite), 3 kg. recovered, fell 22. 12. 1868, 5 p.m., at Moti-ka-nagla, a hamlet of Gurdha Dang, 26° 50′ N., 77° 20′ E., 36 miles S. of Bharatpur, tahsil Biana, Bharatpur State, Rajputana.

18. **Muddoor** (or Maddur). Two stones (spherical hypersthene-chondrite), 2 kg. recovered, fell 21. 9. 1865, 7 a.m., at Anedoddi, 12° 38′ N., 77° 1′ E., 5 miles N. of Maddur, district Mysore, Mysore State.

19. **Myhee Caunta.** Shower of stones (intermediate chondrite), one fragment recovered, fell 30. 11. 1842, 4 p.m., 'between the villages of Jeetala and Mor Monree, in the Myhee Caunta, to the north-east of the city of Ahmedabad'. Ahmadabad (23° 3′ N., 72° 38′ E.) is in Bombay, but I have been unable to identify the villages in Mahi Kantha State on the one-inch map.

20. **Naoki.** Four stones (grey chondrite), 6·683 g. recovered, fell 29. 9. 1928, 5 p.m., at and near Naoki, 19° 15′ N., 77° 0′ E., 4 miles NNW. of Purna River railway station (Hyderabad-Godavari Railway), district Parbhani, Hyderabad State; portions also at Malegaon 1 mile SE., and Kawagaon 1 mile SW. of Naoki. [Min. Abstr., **4**–421.]

21. **Pulsora.** Three stones (brecciated intermediate chondrite), one weighed about 680 g., fell 16. 3. 1863, afternoon, at Pulsora, 23° 22′ N., 75° 11′ E., 6 miles NE. of Ratlam, Ratlam State.

22. **Samelia.** Three irons (coarse octahedrite), 2·461 kg., fell 20. 5. 1921, 5.30 p.m., at and near Shahpura, 25° 40′ N., 74° 52′ E., Shahpura State; portions also at Beshi 1 mile SE., and Beshkali 4 miles WSW. of Samelia, in Banera, Udaipur State, Rajputana. [M.A. **5**–10.]

23. **Shupiyan.** Two stones (brecciated grey chondrite), 5 kg., fell April 1912, at Shapiyun, 33° 43′ N., 74° 50′ E., 24 miles S. of Srinagar, Kashmir State.

24. **Tonk.** Shower of small stones (carbonaceous chondrite), 7·7 g. collected, fell 22. 1. 1911, 3.55 p.m., at Chhabra, 24° 39′ N., 76° 52′ E., Tonk State; near Gugor or Chhabra railway station, Great Indian Peninsular Railway, 28 miles W. of Guna, Central India.

25. **Umbala.** Stone (veined grey chondrite), 100 g., fell in 1822 or 1823, 'about 40 miles to the west of Umbala, between the Jumna and Punjab'. No further information is available, but 40 miles W. of Ambala is now in Patiala State, at about 30° 20′ N., 76° 20′ E.

UNCLASSED

1. **Jemlapur.** Stone (intermediate chondrite), 468 g., found in a curio shop at Beckenham, Kent, in 1913, with slip attached inscribed: 'Meteorite, Jemlapur, Muddera [or Muddesa] Tk [or Ik or Gk], (fell Feb./01).' All efforts to obtain further information at the time (letter and photograph in 'Nature', 1916, vol. 97, p. 241), and letters recently published in the five chief Indian newspapers, have failed to do so.

CEYLON

1. **Mulletiwu.** Shower of stones (spherical chondrite), fell 13. 4. 1795, 8 a.m., at Mullaitivu, 9° 20′ N., 80° 50′ E., on coast 60 miles NW. of Trincomali.

Explanation of Plate XII.

Sketch-map showing the distribution of Indian meteorites. The rings are marked from no. 1 in each Province, e.g. nos. 1–30 in the case of the United Provinces. The black dots with larger numbers 1–25 refer to the Indian States.

C. A. Silberrad: Sketch-map showing Distribution of Indian Meteorites.

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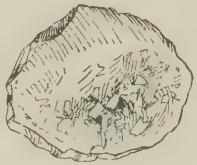

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PROCEEDINGS
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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 19, 1932, *at* 4.15 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

Mr. John Brooke Scrivenor was provisionally re-elected an Ordinary Member of the Society.

The resignation of Mr. J. Reekie was received and accepted. Messrs. A. E. Mitchell and N. W. Wilson were removed from the List of Members in accordance with the terms of the bye-laws.

The Treasurer reported the results of his inquiries as to the cost of obtaining a Royal Charter. It was decided that no action be taken for the present.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 19, 1932, *at* 5.30 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

Twenty Members and two Visitors were present.

The re-election of Mr. J. B. Scrivenor as an Ordinary Member of the Society was confirmed.

Mr. F. N. Ashcroft exhibited photographs and lantern-slides of of some Nova Scotian zeolite occurrences.

The following papers were then read:—

1. A new pallasite from Alice Springs, Central Australia: by Dr. L. J. Spencer (p. 38).

2. An account of British mineral collectors and dealers in the 17th, 18th, and 19th centuries (continued): by Mr. Arthur Russell.

3. Studies on the zeolites. Part III. Natrolite and metanatrolite: by Mr. M. H. Hey (p. 243).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 15, 1932, *at* 4 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Dr. Arthur Ernest Mourant was provisionally elected an Ordinary Member of the Society.

The resignation of Mr. H. B. Milner was received and accepted.

Prof. A. Hutchinson proposed an alteration in the days on which meetings should be held, and it was decided that the meetings in 1933 should be held on Thursdays.

The vacancy in the list of Honorary Members was considered and a voting list was drawn up.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 15, 1932, *at* 5.30 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Twenty-six Members and three Visitors were present.

The election of Dr. A. E. Mourant as an Ordinary Member of the Society was confirmed.

Mr. J. B. Scrivenor exhibited magnesium borate from Kinta, Federated Malay States; and Mr. Arthur Russell exhibited a large specimen of galena and a fine sphere of witherite from Wanlockhead, Dumfriesshire, and orthite crystals from Cefnbychan, Merionethshire.

The following papers were then read:—

1. The distinction of pyrite from marcasite in nodular growths: by Mr. F. A. Bannister (p. 179).

2. On the changed composition of an anorthoclase-bearing rock-glass: by Dr. L. Hawkes and Dr. H. F. Harwood (p. 163).

3. The spherulitic rhyolites of Jersey: by Dr. A. E. Mourant (p. 227).

4. An albitite from Ve Skerries, Shetland Isles: by Dr. F. Walker (p. 239).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 7, 1932, at 4 p.m.

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

The dates of meetings for 1933 were discussed and in pursuance of the decision taken at the last meeting it was decided that these should be held on the following *Thursdays*: January 26, March 23, June 15, and November 9.

The list of Officers and Members of Council to be submitted to the Members for election at the next Anniversary Meeting was considered. The retiring members were: Dr. G. F. Herbert Smith (on completing his third year as Vice-President); and the following Ordinary Members of Council: Dr. A. Brammall, Mr. G. M. Davies, Prof. W. G. Fearnsides, and Miss M. W. Porter. It was decided to ask Sir William Bragg to be Vice-President and failing him Mr. Arthur Russell. For Ordinary Members the result of the ballot was: previous members of Council, Prof. H. L. Bowman and Prof. P. G. H. Boswell; new members, Dr. F. C. Phillips and Dr. W. R. Jones.

The voting list for the vacancy in the list of Honorary Members having been discussed, a ballot was taken which resulted in the selection of Dr. H. S. Washington.

The General Secretary made a brief report on the excursion to Oxford on May 28, which was attended by nineteen members and four guests. The President proposed a hearty vote of thanks to Professor and Mrs. Bowman for their hospitality on that occasion. This was carried unanimously and the General Secretary was instructed to convey the thanks of the Society to Professor and Mrs. Bowman accordingly.

An application from the Deutsche Mineralogische Gesellschaft for an exchange of the 'Mineralogical Magazine' with the 'Fortschritte' was accepted.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 7, 1932, at 5.30 p.m.

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Twenty-one Members and one Visitor were present.

The President announced that Dr. H. S. Washington had been provisionally elected as an Honorary Member, and he asked the

members present for confirmation. On a show of hands Dr. Washington was duly elected.

The following papers were then read :—

1. Legrandite, a new zinc arsenate : by Dr. J. Drugman and Mr. M. H. Hey (p. 175).

2. On the metamorphism produced by the combustion of hydrocarbons in the Tertiary sediments of south-west Persia : by Dr. W. F. P. McLintock (p. 207).

3. Determination of minerals in the Transvaal platinum concentrates by X-ray methods : by Mr. F. A. Bannister, with chemical analyses and syntheses by Mr. M. H. Hey (p. 188).

4. On bultfonteinite, a new fluorine-bearing hydrous calcium silicate from South Africa : by the late Mr. J. Parry, Mr. Alpheus F. Williams, and Dr. F. E. Wright (p. 145).

SPECIAL COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., September 29, 1932, *at* 4.30 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

This meeting was called by order of the President to fill two vacancies in the list of Ordinary Members of Council nominated for the voting list.

The Secretary announced that Sir William Bragg had been unable to accept nomination as Vice-President, and Mr. Arthur Russell had therefore been nominated as instructed by the minute of the Council Meeting of June 7. This had caused one vacancy in the list of Ordinary Members. The second vacancy had been created by the death on September 22 of Dr. F. H. Hatch. The names of various members voted on at the last meeting for nomination were read out, and it was decided to fill the two vacancies by nominating Dr. L. Hawkes and Mr. J. B. Scrivenor.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 1, 1932, *at* 4 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Mr. Mark C. Bandy, Dr. Kenneth Wilson Earle, Miss Doris Livesey Reynolds, and Mr. Charles Arthur Silberrad were provisionally elected Ordinary Members of the Society.

Dr. H. F. Harwood and Mr. A. F. Hallimond were elected auditors.

The Treasurer reported that after consultation with Sir Henry Miers, the Society's holding of 5 % War Loan was converted into $3\frac{1}{2}$ % War Loan in July last in accordance with the Government's conversion offer.

The Annual Report of the Council, submitted by the General Secretary, was read and approved.

Dr. Spencer reported that the Committee appointed on November 4, 1930, to co-operate with the Committee on Nomenclature of the Mineralogical Society of America, had met and considered a report issued in 1932. It was agreed that Dr. Spencer, in the name of the Committee, should communicate direct with the American Committee.

Sir Henry Miers was asked to represent the Society at the celebration of the centenary of the Charter-date of the Philosophical Society of Cambridge.

The deaths of Prof. Louis Duparc (Honorary Member), Mr. George Barrow, Prof. J. W. Gregory, Dr. F. H. Hatch, Dr. G. F. Kunz, and Mr. C. J. Woodward were announced.

GENERAL (ANNIVERSARY) MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 1, 1932, *at* 5.30 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Thirty-four Members and two Visitors were present.

The chairman nominated Dr. W. Q. Kennedy and Dr. A. E. Mourant to act as scrutineers of the voting-papers for the election of Officers and Council.

The elections of Mr. M. C. Bandy, Dr. K. W. Earle, Miss D. L. Reynolds, and Mr. C. A. Silberrad as Ordinary Members of the Society were confirmed.

The General Secretary then read the following:—

Annual Report of Council.

During the session 1931–32 four ordinary meetings have been held. Seventeen papers have been read, and four numbers of the Mineralogical Magazine (Nos. 135–138) have been issued. No. 135 contains the index to vol. 22 and vol. 4 of Mineralogical Abstracts. Numbers 136–138 contain fourteen papers, occupying 206 pages, with eight plates, and 450 abstracts, occupying 144 pages.

The Council regrets to announce the death of Prof. Louis Duparc, an honorary member, who died on October 20, 1932; also of the following ordinary members, Mr. George Barrow, Prof. John Walter Gregory, Dr. Frederick Henry Hatch, Dr. George Frederick Kunz, and Mr. Charles Josiah Woodward. The last named was one of the members of the Crystallological Society. During the year two ordinary members have resigned, and two have been removed from the list of members in accordance with bye-law 8. Five new members have been elected, and one re-elected, and Dr. H. S. Washington has been elected an Honorary Member, leaving the total membership on October 31, 1932, at 222, including nine honorary members.

At the Annual General Meeting held on November 3, 1931, the Council submitted to the membership certain amendments to the bye-laws. These amendments were adopted and came into force forthwith. At the time that these amendments were under discussion the Council was advised that it was desirable that the Capital Monies, representing Composition Fees received, should be separated from the other Capital Monies of the Society. In consequence of this advice a Composition Fees Account has been created and £975 0*s*. 0*d*. 5% War Loan 1929–47 was allocated thereto at the close of the year. This stock, which was purchased at a cost of £1,129 14*s*. 7*d*. covers the Composition Fees received from the foundation of the Society up to December, 31, 1931. The actual amount so received was £1,128 15*s*. 0*d*. The 5% War Loan held by the Trustees, including that allocated to the Composition Fees Account, was converted into 3½% War Loan in accordance with the Government's conversion scheme in July last.

The accounts for the year ending December 31, 1931, showed, after the allocation of £975 5% War Loan 1929–47 to the newly established Composition Fees Account, an excess of assets (exclusive of the Library and stock of publications) over liabilities of £1,133 17*s*. 8*d*. The value of the stock invested in the names of the Trustees was on December 31, 1931, General Reserve £782 10*s*. 1*d*., Composition Fees Account £933 11*s*. 3*d*.

The Society's Library has received during the year 171 parts of periodicals and 14 separate copies of papers. Only 27 volumes have been borrowed. An exchange of periodicals has been entered into with the Deutsche Mineralogische Gesellschaft and Periodico di Mineralogia.

The Nomenclature Committee, appointed on November 4, 1930, has held one meeting to discuss the Report of the Committee appointed by the Mineralogical Society of America, and has reported to the Council.

At the suggestion of Dr. G. F. Herbert Smith inquiries have been made by the Treasurer as to the cost of procuring a Royal Charter, but in view of the expense entailed no further action was taken.

On May 28, nineteen members and four guests paid a visit to the mineral collections and laboratories in the Oxford University Museum. The party was received at the Museum by Prof. H. L. Bowman and his staff, and was afterwards entertained to tea by Prof. and Mrs. Bowman.

In order to suit the convenience of a considerable number of members residing outside London, it has been decided for the future to hold the meetings on Thursdays instead of Tuesdays as heretofore.

On the motion of Prof. H. Hilton, seconded by Mr. Harvey Collingridge, the report was adopted.

The scrutineers reported that fifty voting-papers had been returned to the Secretary, and that the following Officers and Ordinary Members of Council were declared elected :—

President. Sir John S. Flett, K.B.E., M.A., LL.D., D.Sc., F.R.S.
Vice-Presidents. Prof. C. Gilbert Cullis, D.Sc., F.G.S.
Arthur Russell, M.B.E.
Treasurer. F. N. Ashcroft, M.A., F.G.S., F.C.S.
General Secretary. W. Campbell Smith, M.C., T.D., M.A., F.G.S.
Foreign Secretary. Prof. A. Hutchinson, O.B.E., M.A., Ph.D., F.R.S.
Editor of the Journal. Dr. L. J. Spencer, M.A., Sc.D., F.R.S.

Ordinary Members of Council.

A. F. Hallimond, M.A., F.G.S.
Sir Albert E. Kitson, C.M.G., C.B.E., F.G.S.
Prof. W. L. Bragg, O.B.E., M.A., F.R.S.
F. A. Bannister, M.A.
Prof. H. H. Read, D.Sc., A.R.C.S., F.G.S.
Prof. C. E. Tilley, Ph.D., B.Sc., A.I.C., F.G.S.
Prof. P. G. H. Boswell, O.B.E., D.Sc., A.R.C.S., F.R.S.
Prof. H. L. Bowman, M.A., D.Sc., F.G.S.
Dr. L. Hawkes, D.Sc., F.G.S.
Dr. W. R. Jones, D.Sc., F.G.S.
Dr. F. C. Phillips, M.A., Ph.D., F.G.S.
J. B. Scrivenor, I.S.O., M.A., F.G.S.

A vote of thanks to the retiring Members of Council was proposed by the President.

A vote of thanks to the Geological Society of London for the use of the meeting rooms during the year was proposed by Dr. A. E. H. Tutton and seconded by Mr. F. A. Bannister. This was carried unanimously.

[*continued on p. liv.*

MINERALOGICAL

ABSTRACT OF RECEIPTS AND PAYMENTS

Receipts.	£ s. d.	£ s. d.
		GENERAL PUR-
By Balances brought forward from 1931—		
1. At Bankers:		
(*a*) Current Account	25 8 4	
(*b*) Deposit Account	225 0 0	
2. In Office	0 7 2	
		250 15 6
Entrance Fees		4 4 0
Annual Subscriptions—		
1. Current year	159 12 0	
2. Arrears	5 5 0	
3. Advance	7 0 3	
		171 17 3
Sale of Publications—		
1. By Publishers, April 1, 1931–March 31, 1932. Sales at subscription rate £223 0*s.* 0*d.* and other sales £57 10*s.* 0*d.*, less trade discount and commission £74 18*s.* 4*d.*, and distribution charges £12 18*s.* 11*d.*	192 12 9	
2. By Custodian of Stock, 1932. £12 13*s.* 0*d.*, less distribution charges £1 2*s.* 3*d.*	11 10 9	
		204 3 6
Advertisement Fees, £31 11*s.* 8*d.*, less commission £6 6*s.* 4*d.*		25 5 4
Interest on Investments as received—		
1. £640 5% War Loan 1929–47, Inscribed Stock [1]	32 0 0	
2. £105 4% Consolidated Loan 1957, Inscribed Stock	4 4 0	
3. £100 4% Funding Loan 1960–90, Inscribed Stock	4 0 0	
		40 4 0
Deposit Interest		4 0 4
Bonus on conversion of £640 5% War Loan		6 8 0
One half of commission on conversion of £640 5% War Loan returned by Brokers		0 16 0
Small Receipts		0 2 1
Transfers from other accounts—		
1. From Library Fund Account, being the balance to the credit of that account when closed in January 1932	1 2 6	
2. From Composition Fees Account, being Interest on Investments, Bonus on conversion of £975 5% War Loan, and one half of commission on that conversion returned by Brokers	59 14 5	
		60 16 11
		£768 12 11

[1] Now £640 3½% War Loan 1952, Inscribed Stock.

SOCIETY

FOR THE YEAR ENDING DECEMBER 31, 1932

POSES ACCOUNT.

PAYMENTS.	£ s. d.	£ s. d.
To Printing and distributing the Mineralogical Magazine Nos. 136–139 inclusive (Oxford University Press)—		
1. Printing	362 10 9	
2. Illustrations	62 9 3	
3. Authors' Separate Copies	36 10 6	
4. Distribution Charges	15 15 0	
		477 5 6
Printing and distributing notices of Meetings and other annual miscellaneous printing		17 6 3
Miscellaneous Printing, &c. (not annual)—		
1. List of Members (wrapper for)	1 17 6	
2. Notices of Excursion, printing and postage	2 7 6	
3. Treasurer's Notices	2 9 6	
		6 14 6
Expenses at Meetings—		
1. Operator of lantern	2 2 0	
2. Porter	1 0 0	
3. Tea	2 14 6	
		5 16 6
Care of Stock of Publications, J. Mugford, Annual Fee		1 1 0
Editor's Honorarium		50 0 0
Librarian's Honorarium		5 0 0
Postage—		
1. Hon. Secretary	0 19 6	
2. Editor	0 16 8	
3. Hon. Treasurer (not charged)	0 0 0	
4. Librarian	0 1 2	
		1 17 4
Bank charges and other small items		0 4 1
Balance, December 31, 1932—		
1. At Bankers:		
(*a*) Current Account	18 5 5	
(*b*) Deposit Account	185 0 0	
2. In Office	0 2 4	
		203 7 9
		£768 12 11

Examined and compared with vouchers and found correct.

A. F. HALLIMOND } Auditors.
H. F. HARWOOD }

January 18, 1933.

F. N. ASHCROFT, Hon. Treasurer.

BALANCE

DECEMBER

LIABILITIES.	£ s. d.	£ s. d.
To Balance in hand as per Temporary Suspense Account (not published)		
At Bankers, Current Account		0 6 8
Sundry Creditors		0 0 0
Annual Subscriptions received in advance—		
1. Received in 1932 for 1933	6 6 0	
2. Received in 1932 for 1934	0 14 3	
		7 0 3
Excess of Assets over Liabilities		1146 10 10
		£1153 17 9

COMPOSITION FEES ACCOUNT

RECEIPTS	£ s. d.	£ s. d.
By Composition Fees received as per last Account	1128 15 0	
Composition Fees received during year	0 0 0	
		1128 15 0
Income—		
1. Interest on Investments as received—£975 5% War Loan 1929–47, Inscribed Stock	48 15 0	
2. Bonus on Conversion of £975 5% War Loan	9 15 0	
3. One half of Commission on Conversion of £975 5% War Loan returned by Brokers	1 4 5	
		59 14 5
		£1188 9 5

SHEET

31, 1932.

Assets.	£ s. d.	£ s. d.
By Balances—		
I. General Purposes Account:		
1. At Bankers:		
(*a*) Current Account	18 5 5	
(*b*) Deposit Account	185 0 0	
2. In Office	0 2 4	
		203 7 9
II. Temporary Suspense Account (not published)		0 6 8
Sundry Creditors—		
Publishers, Oxford University Press:		
1. Sale of Publications, April 1–Dec. 31, 1932	81 9 5	
2. Advertisement Fees	9 0 5	
		90 9 10
Investments at Broker's Valuation—		
1. £640 3½ % War Loan 1952 Inscribed Stock at 98¾	632 0 0	
2. £105 4 % Consolidated Loan 1957, Inscribed Stock at 106½ 'ex' div.	111 16 6	
3. £100 4% Funding Loan 1960–90, Inscribed Stock at 108½	108 10 0	
		852 6 6
Annual Subscriptions in Arrear valued at		6 6 0
Entrance Fee in Arrear		1 1 0
		£1153 17 9

Note.—The value of the Library, that of the unsold Stock of Publications, and that of the Securities allocated to the Composition Fees Account are not included in the above assets.

January 18, 1933. F. N. ASHCROFT, Hon. Treasurer.

YEAR ENDING DECEMBER 31, 1932.

Payments.	£ s. d.	£ s. d.
To Investments as per last Account—		
£975 5% War Loan 1929–47, Inscribed Stock now converted into £975 3½ % War Loan 1952, Inscribed Stock, Valued by Brokers at £962 16*s.* 3*d.* (98¾)	1128 15 0	
Investments made during year	0 0 0	
		1128 15 0
Income transferred to General Purposes Account		59 14 3
		£1188 9 5

Examined and compared with Vouchers and found correct.

A. F. HALLIMOND } Auditors.
H. F. HARWOOD }

January 18, 1933. F. N. ASHCROFT, Hon. Treasurer.

The following papers were then read :—

1. On stichtite from Cunningsburgh, Shetland Islands: by Prof. H. H. Read and Mr. B. E. Dixon (p. 309).

2. On quartz-kyanite-rocks from Unst, Shetland Islands, and their bearing on metamorphic differentiation : by Prof. H. H. Read (p. 317).

3. A new meteoric iron found near Kyancutta, South Australia : by Dr. L. J. Spencer (p. 329).

4. List of Indian meteorites : by Mr. C. A. Silberrad (p. 290).

5. Meteoric stones from Suwahib, Arabia : by Mr. W. Campbell Smith (p. 334).

6. An account of British mineral collectors, and dealers in the 17th, 18th, and 19th centuries (continued) : by Mr. Arthur Russell.

7. Note on an occurrence of witherite at the Morrison North Pit, Stanley, Co. Durham : by Mr. Arthur Russell.

8. Studies on the zeolites. Part IV. Ashcroftine (kalithomsonite of S. G. Gordon) : by Mr. M. H. Hey and Mr. F. A. Bannister (p. 305).

9. The determination of rock constituents by semi-micro-methods : by Miss W. C. A. Guthrie and Dr. Christina C. Miller (communicated by Dr. F. Walker).